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ST. LOUIS DISPERSION STUDY. VOLUME II. ANALYSIS

James L. McElroy, et al

National Air Pollution Control Administration
Arlington, Virginia

December 1968

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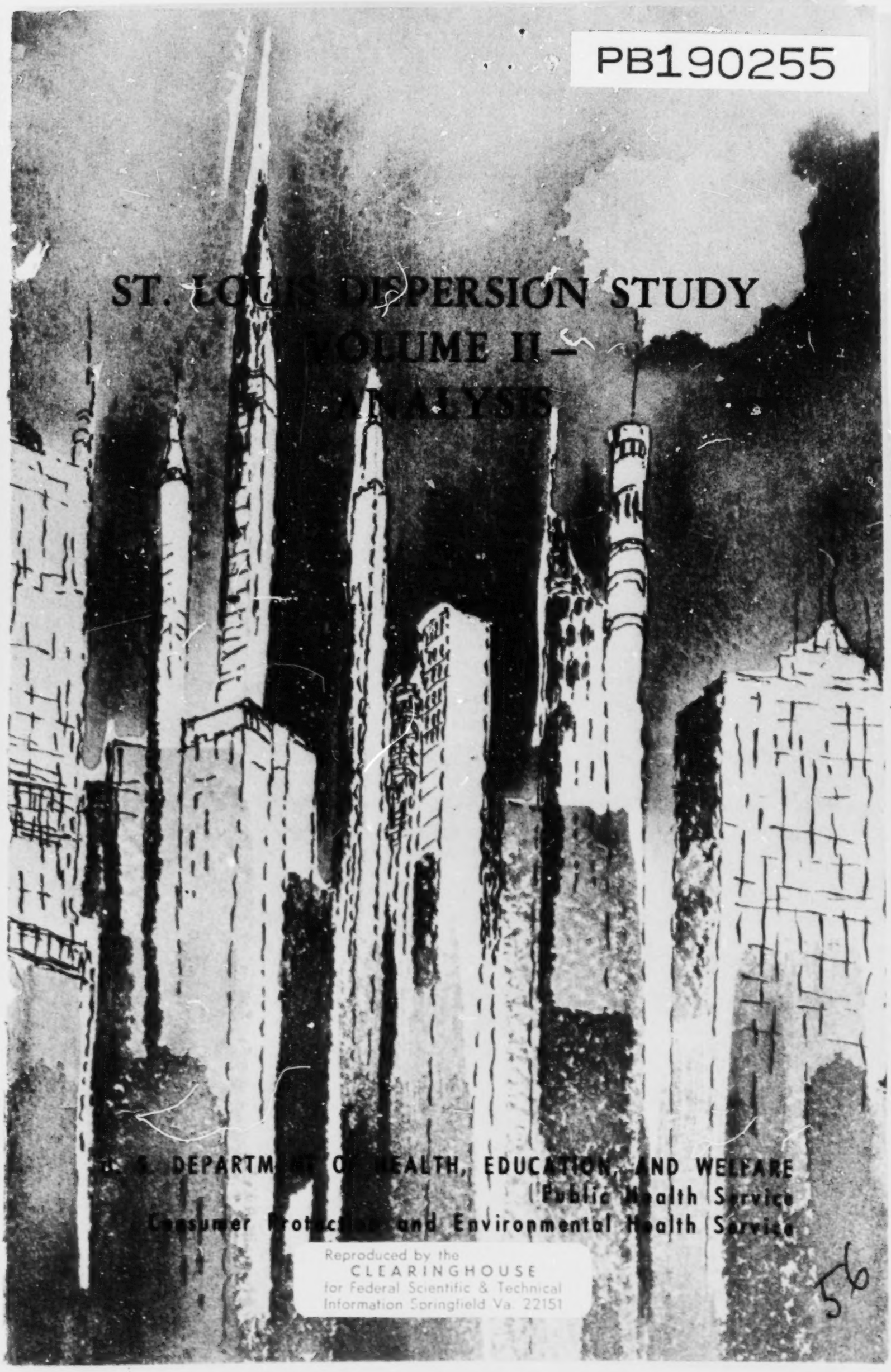

ST. LOUIS DISPERSION STUDY

VOLUME II—
ANALYSIS

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Consumer Protection and Environmental Health Service

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ST. LOUIS DISPERSION STUDY
VOLUME II -
ANALYSIS

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U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
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CONTENTS

ABSTRACT iv
INTRODUCTION 1
DESCRIPTION OF TRACER DATA 3
  Total Dosage at Surface. 3
  Sequential Dosage at Surface 3
  Total Dosage in the Vertical 4
DISPERSION PARAMETERS. 5
  Normalized Axial Concentration 5
  Cross-Wind Parameters 5
  Vertical Parameters 6
  Tabulation of Results 9
  Loss of Tracer Material 9
  Effective Transport Wind Speed 10
METEOROLOGICAL INDICES OF TURBULENCE 15
  Pasquill-Turner Stability Classes 15
  Modified "Brookhaven" Gustiness Classes 15
  Horizontal Wind Direction Fluctuations and Conditions of Vertical Stability 16
  Tabulation of Results 17
RELATION OF DISPERSION PARAMETERS TO METEOROLOGICAL INDICES OF TURBULENCE 19
COMPARISONS WITH OTHER EXPERIMENTAL PROGRAMS . . . 21
INITIAL DIMENSIONS OF TRACER CLOUD 23
CONCLUSIONS AND RECOMMENDATIONS 45
ACKNOWLEDGMENTS 47
REFERENCES 49

ABSTRACT

The primary analyses performed on data collected during low-level tracer experiments conducted over metropolitan St. Louis, Missouri, are described. Values of dispersion parameters derived from the tracer data are related to readily derived or measured meteorological indices of turbulence. The results are graphically presented in terms of best-fit curves as functions of downwind distance and travel time. Comparisons are made with the results of previous diffusion experiments conducted over relatively uncomplicated terrain in open country. It is concluded that for low-level point sources the urban area affects cross-wind dispersion primarily by enhancing the initial size (i.e., close to the source) of the plume. As the plume becomes much larger than the size of eddies created by the local obstructions, the dispersion approaches that associated with flow over open country. In the vertical, significantly enhanced dispersion as well as an enlarged initial spread of the tracer cloud seem to occur; this enhancement in the rate of dispersion over that in open country appears somewhat greater for stable than for unstable meteorological conditions. Values of dispersion parameters from limited tracer experiments in other urban areas are similar to those reported here for St. Louis under the same gross meteorological conditions.

ST. LOUIS DISPERSION STUDY
VOLUME II -
ANALYSIS

INTRODUCTION

The St. Louis Dispersion Study consisted of a series of experiments in which fluorescent zinc cadmium sulfide particles were released and traced across the relatively flat urban area of metropolitan St. Louis. The measurement program began in the spring of 1963 and ended in the spring of 1965. Over this 2-year period 26 daytime and 16 evening experiments were conducted in seven series. Dissemination of fluorescent particles from either of the two pre-selected sites near ground level was usually 1 hour long. For each experiment, measurements of total dosage at the surface were obtained on three nearly circular arcs at distances between 1/2 and 10 miles from the dissemination site. The use of particular arcs varied, usually depending on appropriate forecasts of wind direction and speed. In addition, time-sequential measurements of dosage at the surface were made on each arc at a few locations near the anticipated mean centerline of the tracer cloud. During nine experiments, total dosage was measured at several heights along the tether of a balloon flown at a single site. The site was usually a park or vacant lot between the inner and outer sampling arcs and as near as possible to the anticipated mean centerline. Also, a mesometeorological network composed of three stations on the periphery of the urban area and an instrumented television tower (KMOX) in the downtown area provided continuous records of wind, temperature, and relative humidity. The TV tower was instrumented at three levels to provide information on the vertical gradients of wind and temperature. Single-theodolite (pibal) observations of winds aloft and measurements of winds near the surface were made at the tracer dissemination site; free or tethered radiosonde ascents were made from the roof of a building in the downtown area; and transponder-equipped tetroons were released near the dissemination site. The tetroons were tracked by radar located at Lambert Field, northwest of the metropolitan area.

Volume I of this report (APTD-68-12) presents a detailed description of the experimental equipment and procedures employed in the study, and provides in tabular form the dispersion and related meteorological data collected during the tracer experiments. Because Volume I is mainly data tables, it is not being given general distribution.

Volume II describes the primary analyses performed on the dispersion and related meteorological data collected during the tracer experiments. The main objectives of the analyses were to obtain at least gross estimates of (1) the values of dispersion parameters over urban areas and (2) the relation of these parameters to meteorological indices of turbulence. A secondary objective was to compare the results of the St. Louis Dispersion Study with those of past experimental programs, especially those conducted over relatively "open" country.

DESCRIPTION OF TRACER DATA

TOTAL DOSAGE AT SURFACE

For our purposes, measurements of total dosage were converted to equivalent concentration, χ (particles/m^3), by the equation

$$\chi = \frac{n}{(v)\ (e)\ (D_t)}$$

where:

n = total number of particles (dosage)
v = flow rate of sampler
e = collection efficiency of sampler
D_t = time duration of tracer dissemination

For each sampling arc of an experiment, values of χ were plotted as a function of azimuth direction (degrees) from the tracer dissemination site. A continuous, smoothed curve was drawn through the plotted values. Whenever necessary, curves were extrapolated to zero concentration. In such extrapolations, the continuity and similarity of distributions between sampling arcs were maintained, and, whenever feasible, curves or portions of curves were made to resemble a Gaussian shape.

Multi-peaked or otherwise complex cross-wind distributions of tracer material occasionally occurred, particularly in data from the close-in sampling arcs. Channeling of the airflow due to the spatial distribution of obstructions or locally induced circulations may be largely responsible for this physical appearance of the distributions. Effects of sampler exposure were considered to be insignificant, since the placement of samplers at the nominally designated locations was somewhat random over the 2-year period of the experimental program.

SEQUENTIAL DOSAGE AT SURFACE

Measurements of sequential dosage at the surface were transformed into concentration χ_s by the formula

$$\chi_s = \frac{n}{(v)\ (e)\ (D_i)}$$

where:

n = number of particles (dosage)
v = flow rate of sampler

e = collection efficiency of sampler
D_i = time duration of sequential sampler interval

For each designated location, a plot was made of χ_s as a function of time. The physical appearances of the resulting histograms differed somewhat for daytime and evening experiments.

For daytime experiments, the histograms showed that the number of major concentration peaks decreased with downwind distance from the tracer dissemination site. At inner sampling arcs, concentration was usually continuous with time, though varying widely. At intermediate arcs, the sequential concentration often went to zero, suggesting the occurrence of "puffs" of tracer material. At greater downwind distances, the concentration patterns usually became more uniform in appearance. From these patterns, it is inferred that the horizontally meandering cloud is carried selectively aloft by convective motions. When most of the cloud has been affected by these motions, convective overturning results in a relatively uniform vertical distribution of tracer material.

For evening experiments, the histogram patterns generally were more uniform, although many suggested the existence of weak convective activity. Temperature gradient data from the TV tower, analyzed by the authors and by Schiermeier (1967), also suggest the occurrence of such activity, especially in the lowest 250 feet above the ground. The vertical extent of convective activity probably depends strongly on details of the vertical temperature structure since air flowing into urban areas from the surrounding countryside must always be in a transitional state.

TOTAL DOSAGE IN THE VERTICAL

During nine of the experiments, total dosage was measured at several heights, to a maximum of roughly 1000 feet above ground, along the tether of a balloon flown at a single location. Passage of a squall line during one of these experiments and of a front during another experiment prevented these measurements from being used to develop generalizations. Of the remaining seven experiments (four daytime and three evening), the measurements of one daytime and one evening experiment showed an anomalous increase of dosage with height above the surface. A possible explanation of the anomalies is that on both occasions considerable vertical shear of wind direction occurred in the lower atmosphere. The sampling sites were far from the mean centerlines of the tracer clouds, but with respect to the dissemination site were in the azimuth direction of this shear. The remaining measurements were too limited to allow direct computations of parameter values or to provide definitive information concerning concentration distributions.

DISPERSION PARAMETERS

For the purposes of this report, 32 of the 42 experiments yielded usable dispersion data; 22 of these were conducted in the daytime and 10 in the evening. Many of the excluded experiments yielded usable data for which analysis could not be made in the conventional manner used here. A separate publication is planned to report analyses of these data.

NORMALIZED AXIAL CONCENTRATION

From the plots of equivalent concentration at the surface, χ, (particles/meter^3) versus azimuth (degrees), θ, from the tracer dissemination site for each sampling arc of an experiment, peak or axial values, χ_p, were determined. These values were converted to normalized peak concentrations, $(\chi/Q)_p$ (seconds/meter^3), through division by the tracer emission rate, Q (particles/second).

CROSS-WIND PARAMETERS

From each plot of χ versus θ, values of χ were read at equally spaced azimuth intervals, beginning at an edge of the tracer cloud. The intervals were equivalent to the tracer measurement resolution. Measures of the statistical cross-wind standard deviation, σ_y (meters), and the cross-wind integrated concentration, CIC (particles/meter^2), were then computed from these values.

The equation for the root-mean-square standard deviation, σ, rewritten from Panofsky and Brier (1963), was modified to allow calculations of σ_y:

$$\sigma = \left[\frac{N \ \Sigma f_i \ (I_i)^2 - (\ \Sigma f_i \ I_i)^2}{N^2}\right]^{1/2} \Delta \qquad (1)$$

where:

Δ = frequency class interval
I_i = deviation of class midpoint i from the assumed mean in terms of class intervals
f_i = frequency of the distribution for class interval i
N = total f_i, i.e., Σf_i

When a plot of χ versus θ is considered to be a frequency histogram of χ in terms of θ, the values of χ at the equal azimuth increments may be taken as the mean values of increments for which they are the midpoints. Thus, $\chi_i = f_i$ and $\Sigma \chi_i = N$. The proper Δ is not Δ_θ (azimuth degrees) but rather Δ_y (arc length) written

$$\sigma_y = (\Delta_\theta)\ (\bar{x})\ (\pi/180) \tag{2}$$

where $\bar{x}$, mean arc radius, is defined by $\frac{\Sigma \chi_j x_j}{\Sigma \chi_j}$ and χ_j is the equivalent concentration at a given sampling site along the arc located a distance χ_j from the dissemination site.

With these definitions equation (1) may be rewritten as

$$\sigma_y = \left[\frac{\Sigma \chi_i\ (\Sigma \chi_i\ I_i^{\ 2}) - (\Sigma \chi_i\ I_i)^2}{(\Sigma \chi_i)^2}\right]^{1/2} \left[\Delta_\theta\right]\left[\frac{\Sigma \chi_j x_j}{\Sigma \chi_j}\right]\left[\frac{\pi}{180}\right] \tag{3}$$

Surface cross-wind integrated concentration, CIC_s, defined as $\int_{-\infty}^{\infty} \chi(y)dy$ was approximated by $\Sigma \chi_i \Delta_y$. When Δ_y from equation (2) is substituted into the latter, the appropriate formulation becomes

$$CIC_s = \sum \left[(\chi_i)\ (\Delta_\theta) \left(\frac{\Sigma \chi_j x_j}{\Sigma \chi_j}\right) \left(\frac{\pi}{180}\right)\right] \tag{4}$$

VERTICAL PARAMETERS

Estimates of vertical dispersion parameters were based on the surface tracer measurements and hence represent only "effective" values. As previously noted, the measurements of tracer material in the vertical were too limited for direct computation of vertical parameter values. The rationale for describing dispersion in the vertical differed for daytime and evening experiments.

Daytime Experiments

For each arc of a daytime experiment, a derived estimate of the vertical standard deviation, σ_z (meters), was computed from the appropriate mass continuity equation, assuming no loss of tracer in transit, uncorrelated horizontal and vertical tracer distributions, and a Gaussian distribution of material in the vertical. This equation may be written as

$$Q = \int_0^{\infty}\int_{-\infty}^{\infty} \bar{u}\ \chi(y)\ \ \chi(z)\ \ dy\ \ dz \tag{5}$$

where:

Q = quantity of tracer material disseminated per unit time
$\bar{u}$ = effective transport wind speed

Since $\bar{u}$ is assumed to be independent of y and z and $\int_{-\infty}^{\infty} \chi(y)dy$ is CIC_s,

$$\frac{Q}{\bar{u}\ CIC_s} = \int_0^{\infty} \chi(z)\ \ dz$$

With $\chi(z) = 1/2 \exp(-z^2/2\sigma_z^2)$, i.e., the function for a Gaussian distribution with perfect reflection of the tracer material at the ground, the appropriate integration yields

$$\frac{Q}{\bar{u}\ CIC} = \frac{\sqrt{2\pi}}{2}\ \sigma_z \qquad (6)$$

or $$\sigma_z = \frac{2Q}{(CIC_s)\ (\bar{u})\ (\sqrt{2\pi})}$$

Estimates of the effective transport wind speed, $\bar{u}$, were obtained from mean tetroon trajectories, except when the surface projected position of the tetroon differed significantly from the centerline of the tracer cloud or when the elevation of the tetroon was beyond the top of the mixing layer that was assumed to contain the bulk of tracer material. On these other occasions, values of $\bar{u}$ from mean wind profiles measured at the TV tower or by pilot balloon ascents were substituted. In experiments for which suitable sequential dosage samples were obtained, the measurements of $\bar{u}$ based on observed wind or tetroon data, especially the latter, agreed well with $\bar{u}$ values based on the timing of tracer cloud passages across sampling arcs. Estimates of travel time, t, of the tracer cloud to various arcs were made from

$$t = \bar{x} / \bar{u} \qquad (7)$$

where:

$\bar{x}$ = mean arc distance from dissemination site

Evening Experiments

For the evening experiments, which were conducted under more stable meteorological conditions, the vertical profiles of wind and tracer material were assumed to be significantly interrelated. In view of this assumption and of the limitations of the tracer data, a simple box model was derived to describe dispersion in the vertical. Basically, the model assumes that the tracer material is uniformly mixed to some height h. The depth of the uniformly mixed layer, h, was assumed to increase linearly with travel time, t, of the tracer cloud between arcs. That is,

$$h_2 = h_1 + K_{12}(t_2 - t_1) \qquad (8)$$

where the subscripts refer to the particular arcs and K_{12} is a constant for these arcs for a particular experiment. The wind profile was assumed to be of the form $u_z = az^n$ where z is height and a and n are constants for each experiment. These particular assumptions appeared reasonably to characterize the appropriate tracer and meteorological measurements.

For the simple box model, equation (5) reduces to

$$Q = (CIC_s)\ (\bar{u}_h)\ (h) \tag{9}$$

or $$h = Q/CIC_s\ \bar{u}_h$$

where $\bar{u}_h$ is the effective mean transport wind through depth, h, at a particular arc. The appropriate $\bar{u}_h$ for h at each arc was defined by the relation

$$\bar{u}_h = \frac{\int_o^h \chi(z) u_z\ dz}{\int_o^h \chi(z)\ dz} \tag{10}$$

where $\chi(z)$ in this case is a constant, C.

Integration of this equation with the substitutions $u_z = az^n$ and $\chi(z) = C$ yields

$$\bar{u}_h = \frac{ah^n}{n + 1} \tag{11}$$

When this value for $\bar{u}_h$ is substituted into equation (8), the relation becomes

$$h = \left[\frac{n + 1}{a}\ \frac{Q}{CIC_s}\right]^{\frac{1}{n + 1}} \tag{12}$$

Now it is necessary to determine horizontally and vertically averaged travel speeds, $\bar{\bar{u}}_h$, based on the horizontal variation of vertically averaged speeds, $\bar{u}_h$. Since h from equation (8) has been defined as a function of t,

$$\bar{\bar{u}}_h = \frac{\int_{t_1}^{t_2} \bar{u}_h\ (t)\ dt}{\int_{t_1}^{t_2} dt} \tag{13}$$

where t_1 and t_2 are travel times from the dissemination site to particular arcs. From equations (11) and (8),

$$\bar{\bar{u}}_h = \frac{\int_{t_1}^{t_2} \left[h_1 + K_{12}(t_2 - t_1)\right]^n dt}{\int_{t_1}^{t_2} dt} = \frac{a\left(h_2^{n+1} - h_1^{n+1}\right)}{(n + 1)^2 (h_2 - h_1)} \tag{14}$$

where, again, the subscripts indicate particular arcs.

For particular arcs

$$\bar{\bar{u}}_h = \frac{\bar{x}_2 - \bar{x}_1}{t_2 - t_1} \tag{15}$$

where $\bar{x}$ is the mean distance from dissemination site to an arc and t is the corresponding travel time based on the appropriate value of $\bar{u}_h$. Combining equations (14) and (15),

$$t_2 - t_1 = \frac{(\bar{x}_2 - \bar{x}_1)(h_2 - h_1)(n+1)^2}{a\left(h_2^{\,n+1} - h_1^{\,n+1}\right)} \tag{16}$$

For each evening experiment, the coefficients a and n were first determined from mean wind profiles measured at the downtown TV tower or by pilot balloon ascents, after which the h for the appropriate sampling arcs was computed from equation (12). A value for $\bar{u}_h$ corresponding to each h was calculated from equation (11), and travel times between arcs were determined from equation (16).

TABULATION OF RESULTS

Symbols used in the foregoing calculations are listed in Table 1, and dispersion data resulting from the calculations are summarized in Table 2. In addition, in Table 2 values of an "equivalent" Gaussian σ_z, i. e., $2h/\sqrt{2\pi}$, are presented for evening experiments in order to permit a single analysis of dispersion in the vertical.

LOSS OF TRACER MATERIAL

Since disseminations were from near ground level, the loss of tracer material due to deposition or fallout was thought to be a possibility. For the analyses reported herein, such losses would most noticeably affect estimates of vertical dispersion parameters and of axial concentration. A special study (Vaughan and McMullen, 1968) was conducted to assess the magnitude of deposition or fallout that occurred during the St. Louis tracer experiments under various meteorological and ambient air pollution conditions. The assessment was based on statistical comparisons of percentages of fluorescent particles in class-size groupings between samples collected at the various downwind distances and between these collected samples and the standard "lot" disseminated. The findings indicated that in general significant losses of tracer material did not occur in transit. An apparent loss of small particles in the size range less than 1.5 microns did occur with distance under stable meteorological conditions. This loss seemingly resulted from background obscuration of collected particles during prolonged sampling times at greater distances, and not from deposition or fallout. In the St. Louis study, particles with less than 1.5-micron diameters constituted from 20 to 30 percent of the total mass released during each experiment.

In addition, tracer material collected by samplers may not be measured because of loss of fluorescence, particularly when exposed to high humidity and ultraviolet radiation. A recent study (Grinnel, 1965) has demonstrated that the loss in fluorescence of the type of tracer material utilized in St. Louis is no more than 5 percent.

EFFECTIVE TRANSPORT WIND SPEED

As previously discussed, for daytime experiments a single effective transport wind seemed to exist and was represented best by the mean tetroon trajectory, when the tetroon was found in the airflow dispersing the tracer cloud. It was assumed that during the more stable conditions of the evening experiments the vertical profiles of wind and tracer distribution were interrelated, resulting in a transport wind increasing with vertical spreading of the tracer cloud, and thus with travel time.

Instrumental measures of wind speed over tracer dissemination periods were qualitatively evaluated in terms of mean transport wind speeds. Values computed from average pilot balloon observations were of limited use, since deviations from the average (at a particular level) usually were a significant fraction of that average. Wind speed measurements at the tracer dissemination sites provided insufficient data to permit meaningful comparisons with other wind data. Wind speeds measured at about 60 feet above ground at the peripheral sites and at the 127-foot level of the downtown tower were consistently lower than both the daytime and evening effective transport wind speeds. Measurements at the 255-foot level of the tower, during the limited number of experiments for which this wind equipment was operating, usually were of the appropriate magnitude for both daytime and evening effective transport winds. Although measurements at the 459-foot level of the tower usually provided better estimates of daytime transport wind speeds than did measurements at the 255-foot level, they generally overestimated evening transport wind speeds.

Table 1. LIST OF SYMBOLS DESCRIBING DISPERSION DATA

$\bar{x}$	Downwind distance from dissemination site
t	Travel time from dissemination site
σ_y	Cross-wind standard deviation of tracer material
σ_z	Effective vertical standard deviation of tracer material
h	Height of uniformly mixed layer
$(\chi/Q)p$	Relative axial concentration
$\bar{u}$	Effective transport wind speed
u	Wind speed at height z
z	Height
a, n	Empirical constants

Table 2. SUMMARY OF DISPERSION DATA

Experiment No.	Diurnal period	Arc No.	$\bar{x}$, m	t, sec	σ_y, m	σ_z, m	h, m	$(X/Q)_p \times 10^{-8}$, sec/m^3	$\bar{u}$, m/sec	$u = az^n$
2	Day	1	732	105	87	152		430.0		
		2	3152	453	268	559		38.6	7.0	
		3	6445	926	498	4134		2.34		
3	Day	1	761	81	152	56		428.0		
		2	3156	337	399	220		57.3	9.4	
		3	6770	722	717	890		5.06		
4	Day	1	882	102	189	77		341.0		
		2	3323	385	451	529		23.4	8.8	
		3	7590	879	692	1429		4.02		
5	Day	4	1937	575	596	1943		12.8		
		5	4267	1266	1094	1672[a]		7.44[a]	3.4	
		6	8065	2393	1908	1485[a]		4.46[a]		
6	Day	4	2022	479	379	2901		6.55		
		5	4286	1016	557	1732[a]		7.86[a]	4.2	
		6	7938	1882	806	1154[a]		8.51[a]		
7	Day	4	1994	361	340	997		19.6		
		5	4258	772	599	4237		2.52	5.5	
		6	7999	1450	702	2100[a]		4.27[a]		
8	Day	4	1994	274	282	263		68.0		
		5	4171	572	444	765		13.4	7.3	
		6	7988	1096	855	952[a]		4.98[a]		
9	Day	1	715	112	145	101		351.0		
		2	3296	516	420	625		18.2	6.4	
		3	6607	1034	732	1238		5.17		

[a]Values considered to be significantly affected by a limited mixing layer in the vertical.

Table 2 (continued). SUMMARY OF DISPERSION DATA

Experiment No.	Diurnal period	Arc No.	$\bar{x}$, m	t, sec	σ_y, m	σ_z, m	h, m	$(x/Q)_p \times 10^{-8}$, sec/m^3	$\bar{u}$, m/sec	$u = az^n$
11	Day	4	1998	313	301	323		48.6		
		5	4197	658	615	814		10.2	6.4	
		6	7964	1249	681	1511		4.48		
12	Evening	4	2032	628	126	98	123	542.0	4.9	
		5	4294	1115	212	86	107	40.3	4.5	$0.68z^{0.49}$
		6	8058	1747	302	224	280	72.6	7.3	
14	Day	4	2030	155	262	123		70.5		
		5	4157	317	528	459		13.4	13.1	
		6	7932	605	729	637		6.85		
16	Evening	1	710	181	123	64	80	614.0	5.3	
		2	3241	529	490	277	346	39.8	8.7	$1.58z^{0.34}$
		3	6404	856	497	470	589	23.7	10.4	
18	Evening	1	914	369	102	24	30	3530.0	4.8	
		2	3377	975	298	65	81	342.0	4.7	$1.38z^{0.34}$
		3	7200	1645	343	173	217	78.5	6.6	
19	Day	1	712	132	159	149		314.0		
		2	3198	594	657	999		10.4	5.4	
		3	6440	1196	972	3180		2.70		
20	Day	1	823	300	182	480		146.0		
		2	3284	1197	519	17930		1.82	2.7	
		3	7421	2704	1055	3445[a]		3.65[a]		
21[b]	Day	4	1994	465	319	931		24.2		
		6	7984	1862	2779	544		11.6	4.3	
		7	16935	3949	6430	725		4.59		

[a]Values considered to be significantly affected by a limited mixing layer in the vertical.

[b]Values of dispersion parameters not used in the establishment of generalizations; meandering wind or changing mean wind resulted in inflated values of σ_y.

Table 2 (continued). SUMMARY OF DISPERSION DATA

Experiment No.	Diurnal period	Arc No.	$\bar{x}$, m	t, sec	σ_y, m	σ_z, m	h, m	$(x/Q)_p \times 10^{-8}$, sec/m^3	$\bar{u}$, m/sec	$u = az^n$
22	Day	1	945	206	162	104		472.0		
		2	3378	738	450	1771		9.45	4.6	
		3	7370	1610	1022	1222[a]		6.63[a]		
23	Day	1	825	151	121	99		486.0		
		2	3274	601	374	984		19.4	5.4	
		3	7601	1395	722	4112		1.81		
24	Day	1	949	90	160	44		428.0		
		2	3384	320	326	343		24.1	10.6	
		3	7434	703	570	2418		2.28		
25	Day	1	698	299	151	516		212.0		
		2	3245	1388	814	1204[a]		14.3[a]	2.3	
		3	6384	2732	1252	1106[a]		8.79[a]		
28	Day	4	2019	427	350	2148		10.7		
		5	4238	897	476	3466		4.93	4.7	
		7	15960	3379	1470	1241[a]		4.10[a]		
30[b]	Evening	4	1923		381	174	217	137.0		
		5	4274		615	192	240	76.2		
		6	8291		780			8.89		
31	Day	1	940	144	138	56		604.0		
		2/6	3371	516	270	2535		7.22	6.5	
		7	13375	2048	910	1982		2.83		
32[b]	Evening	1	643	245	176	82	102	591.0	3.6	
		2	3236	853	659	196	245	46.9	5.0	$0.91z^{0.36}$
		3	6440	1461	1169	290	363	31.5	5.7	

[a]Values considered to be significantly affected by a limited mixing layer in the vertical.

[b]Values of dispersion parameters not used in the establishment of generalizations; meandering wind or changing mean wind resulted in inflated values of σ_y.

Table 2 (continued). SUMMARY OF DISPERSION DATA

Experiment No.	Diurnal period	Arc No.	$\bar{x}$, m	t, sec	σ_y, m	σ_z, m	h, m	$(X/Q)_p \times 10^{-8}$, sec/m^3	$\bar{u}$, m/sec	$u = az^n$
33	Evening	1	959	348	68	65	81	1710.0	4.6	
		2	3398	732	113	144	180	244.0	7.9	$0.40z^{0.68}$
		3	7647	1234	298	109	136	140.0	6.5	
35	Day	1	734	88	58	250		271.0		
		2	3245	391	181	662		31.6	8.3	
		3	6395	770	322	597[a]		19.0[a]		
36[b]	Day	1	620	87	152	85		374.0		
		2	3236	452	744	430[a]		16.2	7.2	
		3	6833	955	1194	661[a]		6.56[a]		
37	Evening	1	753	224	54	68	85	2070.0	4.7	
		2	3162	644	205	171	213	145.0	6.6	
		3	6514	1077	289	345	431	41.5	8.7	$1.16z^{0.39}$
40	Day	1	733	772	120	147		233.0		
		2	3207	316	474	872		7.87	10.1	
		3	6445	635	645	1211		5.14		
41	Evening	1	627	380	207	66	82	1330.0	2.6	
		2	3223	1262	370	102	127	253.0	3.3	
		3	7459	2566	588	98	122	166.0	3.2	$0.35z^{0.56}$
42	Evening	4	1989	220	202	97	121	146.0	12.8	
		5	4205	372	413	154	193	37.2	17.4	$1.18z^{0.51}$
		6	7501	538	665	204	255	16.1	19.9	
43	Evening	1	757	94	101	63	91	515.0	11.3	
		2	3186	298	372	304	380	20.2	13.5	$5.87z^{0.12}$
		3	6607	546	699	420	526	7.27	14.0	

[a]Values considered to be significantly affected by a limited mixing layer in the vertical.

[b]Values of dispersion parameters not used in the establishment of generalizations; meandering wind or changing mean wind resulted in inflated values of σ_y.

METEOROLOGICAL INDICES OF TURBULENCE

The calculated values of dispersion parameters were related to several readily measured or derived meteorological indices of turbulence. These indices included stability classes, gustiness classes based on patterns of wind direction fluctuations, and a classification based jointly on measures of wind direction fluctuations and conditions of vertical stability. Values of the indices were determined for semi-rural or peripheral locations as well as for urban locations. This approach allows at least qualitative inferences concerning the applicability of the various indices and of station locales in describing dispersion over urban areas.

PASQUILL-TURNER STABILITY CLASSES

In the scheme devised by Pasquill (1961) and later slightly modified by Turner (1964), the diffusive ability of the lower atmosphere is represented by stability classes determined jointly from estimates of net radiation and wind speed . Determinations of these stability classes over periods of tracer dissemination were made for three wind measurement locations in the St. Louis area: the lower level (127 feet above ground) on the TV tower, the peripheral site west of downtown, and the Weather Bureau Airport Station at Lambert Field in comparatively rural surroundings. The net radiation estimates were based on solar altitude, obtained from the Smithsonian Meteorological Tables (1963), and cloud cover and ceiling height, taken from records of hourly observations at the airport.

The use of Pasquill-Turner stability classes for peripheral and urban locations may, of course, be questioned, since the scheme was devised primarily for application over relatively open country. Also, information on cloud cover at the airport may not always be appropriate for the other locations.

MODIFIED "BROOKHAVEN" GUSTINESS CLASSES

In the gustiness classification scheme due to Singer and Smith (1953) at Brookhaven National Laboratory, the diffusive ability of the lower atmosphere is described by the range and rapidity of horizontal wind direction fluctuations; a less detailed scheme had been designed previously by Giblett et al. (1932) for use at Cardington. The range furnishes an estimate of the turbulent velocity component in the cross-wind direction and hence of cross-wind dispersion. The rapidity of the fluctuations also indicates the general degree of vertical stability and thus of dispersion in the vertical.

The basic Brookhaven gustiness classes were used in St. Louis,

but different class limits on the ranges of wind direction fluctuations were adopted. Although the St. Louis wind sensors were the same type as those used at Brookhaven, they were located near larger roughness elements and usually nearer the ground. In addition to the urban (lower level on TV tower) and peripheral sites discussed earlier, wind data for the upper level (459 feet above the ground) of the TV tower were utilized also. With these additional data, comparisons can be made between wind direction fluctuations at 127 feet, slightly above nearby building tops, and those at 459 feet, well above the buildings. For each site, range limits for the specific classes were derived from appropriate analog traces obtained from a climatological analysis of the (analog) records and were, without exception, greater than those found by Singer and Smith (1953) at the Brookhaven site.

HORIZONTAL WIND DIRECTION FLUCTUATIONS AND CONDITIONS OF VERTICAL STABILITY

This joint meteorological index employs the standard deviation of horizontal wind direction fluctuations, σ_θ, and a direct estimate of vertical stability expressed as a gradient Richardson number. Indices based partially or totally on these elements have been applied by such investigators as Cramer (1959), Fuquay et al. (1964), and Slade (1965) to organize dispersion data from other experimental programs.

Estimates of σ_θ over the tracer dissemination periods were made from frequency histograms of azimuth angle derived from records of the analog wind traces. Since the chart speed of wind recorders was a slow 3 inches per hour, portions of the analog traces were occasionally "painted" (i.e., the more commonly occurring azimuth directions). Frequencies for the "painted" azimuth angles were extrapolated from those of the "non-painted" angles under the assumption that the frequency distributions of azimuth angle were Gaussian or resulted from sums of Gaussian distributions.

Comparisons of these values of σ_θ with the extreme, third highest, and fifth highest ranges of wind direction fluctuations over the tracer dissemination periods showed statistically linear relationships for each range for each meteorological site. Linear correlation coefficients varied from 0.8 to slightly over 0.9, the higher correlations generally occurring for the peripheral and upper-level urban locations. Somewhat better correlations were attained with the third highest range than with the extreme or fifth highest ranges. Average values of the ratio of range to σ_θ for the extreme, third highest, and fifth highest range were, respectively, about 7.5, 6.0, and 5.5. The value of 7.5 for the extreme range is slightly different from the 6.0 found by Markee (1963) and Slade (1965) for other locations and exposures.

Estimates of stability were based on wind and temperature measurements at the downtown TV tower or temperature measurements from the downtown radiosonde ascents. Lapse rates, stability ratios, and various forms of the gradient Richardson number for several layers in the lower atmosphere were considered. Thorough evaluation of these

parameters was difficult because of incomplete data. A limited appraisal, however, indicated that the most meaningful parameter was the "bulk" Richardson number Ri_B. Fortunately, adequate data were available to compute this value for most experiments. The Ri_B was based on temperature and wind measurements at the 127- and 459-foot levels of the TV tower. Temperature information from the radiosonde ascents was substituted when the corresponding tower data were missing. Following Lettau (1957), the Ri_B may be defined:

$$Ri_B = \frac{g}{\bar{T}} \frac{[\Delta T/\Delta Z + \Gamma_d] \quad Z^2}{\bar{v}^2}$$

where:

g	=	acceleration of gravity
ΔT	=	temperature difference between top and bottom of the layer
ΔZ	=	height difference between top and bottom of the layer
$\bar{T}$	=	mean absolute temperature through the layer
Γ_d	=	dry adiabatic temperature lapse rate
Z	=	height of upper anemometer
$\bar{v}$	=	mean speed for anemometer at height Z

Originally, a measure of a transport wind speed, $\bar{u}$, was also incorporated into the joint index; its utilization as an additional parameter or in the form $\sigma_\theta \bar{u}$ generally increased data scatter. It should be noted, however, that the tracer experiments were not usually conducted under very strong or very light wind speed conditions, resulting in a reduction in the overall and perhaps within-class range of $\bar{u}$. Dispersion in the cross-wind and in the vertical were better ordered by σ_θ and Ri_B jointly than by either alone. Axial concentrations also were better represented by this joint classification than by σ_θ or Ri_B alone.

TABULATION OF RESULTS

For each of the experiments, values of the meteorological indices at the locations specified in the preceding sections are presented in Table 3. Values of Ri_B denoted with superscripts were those that were inconsistent with all other coincident measures of stability, e.g., Pasquill-Turner classes or gustiness classes. Without exception, these inconsistencies were for cases in which the radiosonde temperature data were substituted for missing TV tower data.

Table 3. SUMMARY OF METEOROLOGICAL INDICES

Experiment No.	Ri_B	σ_θ, azimuth degrees			Pasquill-Turner classes			Modified Brookhaven gustiness classes		
		TV tower (127 ft)	TV tower (459 ft)	Peripheral site	TV tower (127 ft)	Lambert Field	Peripheral site	TV tower (127 ft)	TV tower (459 ft)	Peripheral site
2		21	15	15	D	C	C	B1'	B1'	B1'
3	-0.05	17	14	23	D	D	D	B1'	B1'	B2'
4	-0.03	19	15	19	C	C	C	B1'	B1'	B1'
5	-0.25	33	22	18	B	B	B	B2'	B2'	B1'
6	-0.13	20		23	D	D	C	B1'		B2'
7	0.03[a]	29		17	B	C	C	B2'		B1'
8	-0.07	20	15	17	C	C	C	B1'	B1'	B1'
9	-0.08	21	15	20	C	C	C	B1'	B1'	B2'
11		25		17	C	D	C	B2'		B1'
12		13		10	E-F	E-F	E-F	D'		D'
14	-0.04	19		14	D	D	D	B1'		B1'
16	0	17	15	12	D	D	D	C'	C'	C'
18	0.14	8	5	7	E-F	E-F	E-F	D'	D'	D'
19		25	20	19	C	C	C	B2'	B2'	B1'
20	0[a]	26	26	32	B	B	B	B2'	B2'	B2'
21	0.08[a]	31	26	15	B	C	B	B2'	B2'	B1'
22	-0.51	17	14	17	C	C	C	B2'	B2'	B1'
23	-0.10	18	15	21	C	D	C	B1'	B1'	B2'
24	0.01	20	15	14	C	C	C	C'	C'	C'
25	-0.02	31	24	35	A	B	A	B2'	B2'	B2'
28	-0.40	24		20	B	D	C	B2'		B1'
30					E-F	E-F	E-F	D'	D'	D'
31	-0.11	19	14	16	B	B	C	B1'	B1'	B1'
32	-0.03	19	17		D	D	D	B1'	B1'	
33	-0.03	13	8	13	E-F	E-F	E-F	D'	D'	D'
35	-0.01	15	12	12	D	D	D	C'	C'	C'
36	-0.02	25	17	15	D	D	D	B2'	B1'	B1'
37	0.01	13	12	11	D	D	D	D'	D'	D'
40	-0.05	21	20	18	D	D	D	B1'	B2'	B1'
41	0.12	12	10	12	E-F	E-F	E-F	D'	D'	D'
42	0	15		13	D	D	D	C'		C'
43	-0.01	15	13	14	D	D	D	C'	C'	C'

[a]Values considered to be doubtful in view of other independent measures of stability during the experiment.

RELATION OF DISPERSION PARAMETERS TO METEOROLOGICAL INDICES OF TURBULENCE

Values of σ_y, σ_z, $(\chi/Q)_p$, and $(\chi/Q)_p\bar{u}$ were plotted against downwind distance, x, and travel time, t. For daytime experiments, $\bar{u}$ was based on tetroon speeds; for evening experiments, it was $\bar{u}_h$ (see Vertical Parameters). The dispersion data points were grouped according to values of the meteorological indices determined for each of the previously mentioned locations. Best-fit curves through the data groupings were approximated by eye in view of the small sample size. Linear curves were used since, for the arc distances and travel times represented in the data, few indications of discernible non-linearity were noted. Data points in correlograms involving σ_z and axial concentration were ignored in the determination of best-fit lines when a restriction to vertical mixing (e.g., a temperature inversion aloft) was thought to be affecting the concentration. For such cases the appropriate data in Table 3 are denoted with a superscript a. Information concerning the depth of a mixing layer was obtained from the downtown radiosonde ascents and less frequently from the regular Weather Bureau rawinsonde ascents at Columbia, Missouri, or Peoria, Illinois. The determination that a particular mixing depth affected the dispersion data was made from a consideration of the mixing depth, the growth rate of σ_z and the travel time or downwind distance. Unfortunately, sufficient definitive information was not available to permit a detailed analysis of these cases.

Correlograms of σ_y, σ_z, $(\chi/Q)_p$, and $(\chi/Q)_p\bar{u}$ versus downwind distance in terms of σ_θ and Ri_B for the lower-level urban location are shown in Figures 1 through 4. Similar plots in terms of travel time are presented as Figures 5 through 8. Also, for this urban site, correlograms of σ_y, σ_z, and $(\chi/Q)_p$ versus downwind distance are given in Figures 9 through 11 as functions of Pasquill-Turner stability classes; as functions of modified Brookhaven gustiness classes they are given in Figures 12 through 14. Relations (not shown) in terms of travel time for these other indices were similar to those in Figures 5 through 8.

The scatter of dispersion data points about best-fit lines was greater in terms of meteorological indices computed at peripheral or semirural locations than for the same indices at the lower-level urban locations. Relationships for the dispersion data in terms of indices at the upper-level urban location were similar to those in terms of the indices for the corresponding lower-level location.

In Figures 1 through 14 the following additional features are worthy of specific note:

1. The ordering of data was poorest for the close-in sampling arcs at which multi-peaked or otherwise complex distributions in the cross-wind occurred in greater proportion than at more distant arcs. As previously noted, channeling of the airflow due to various locally induced circulations may be largely responsible for the appearance of such distributions.

2. The scatter of data points about best-fit lines was much greater in σ_z than in the other correlograms. Since the actual vertical distributions of tracer material were largely unknown, the relative magnitude of such scatter was not altogether unexpected.

3. When plotted according to travel time, data were grouped best into only "stable" and "non-stable" regimes, except for σ_z, which was ordered about as well by travel time as by downwind distance.

4. In an earlier preliminary analysis of the dispersion data, Pooler (1966) found that values of σ_y, ordered only according to daytime and evening categories, were grouped about equally well in terms of downwind distance and of travel time, as shown in Figures 1 and 5. In these figures daytime is indicated with a very few exceptions by those points for which $Ri_B \leq 0.01$. As illustrated in Figures 2 and 6, the ordering of σ_z in terms of daytime and evening categories is better in terms of travel time than of downwind distance.

5. Values of σ_z and axial concentration that were considered to be significantly affected by a restrictive mixing layer were usually smaller and larger, respectively, than their non-affected counterparts under similar meteorological conditions.

6. Only a slight improvement in ordering of data points was achieved through normalizing $(\chi/Q)_p$ by $\bar{u}$. Since, however, as was noted earlier, the range of likely $\bar{u}$'s is not fully represented in the data here, the generality of this result and of that involving the ordering of σ_z with distance and time may require further verification.

7. The scatter of data points about best-fit lines was considerably greater for Pasquill-Turner stability classes than for the other indices. For the modified Brookhaven gustiness classes and the joint classes of σ_θ and Ri_B, the scatter of data points about best-fit lines was quite similar.

COMPARISONS WITH OTHER EXPERIMENTAL PROGRAMS

The results (i.e., the derived dispersion relationships) of the St. Louis tracer experiments can be compared with those of past "open country" programs for which the dispersion parameters are described by comparable meteorological indices. Specifically, the St. Louis results based on values of σ_θ and Ri_B (Figures 1 and 3) are related to those of the Green Glow - Series 30 experiments (Fuquay et al., 1964); the results according to Pasquill-Turner stability classes (Figures 9 and 10) are compared with those of several programs as summarized by Pasquill (1961), modified slightly by Gifford (1961) and presented by Hilsmeier and Gifford (1962); and the St. Louis results according to modified Brookhaven gustiness classes (Figures 12 and 13) are related to those of the Brookhaven experimental program (Singer and Smith, 1966). These comparisons (Green Glow, Pasquill-Turner stability, and Brookhaven gustiness) are illustrated in Figures 15 through 17.

The analysis by Fuquay et al. (1964) is in terms of travel time. In view of the St. Louis experimental results, the Green Glow - Series 30 data were analyzed in terms of downwind distance (Figure 15). Of the meteorological parameters considered (σ_θ, $\bar{u}$, $\sigma_\theta \bar{u}$, and a gradient Richardson number), dispersion in the cross wind for Green Glow - Series 30 was best described by σ_θ alone. Peak exposure (axial concentration) was best represented by joint measures of σ_θ and the Richardson number; peak exposure normalized by a $\bar{u}$ was not ordered as well. Data reported for the 12.8- and 25.6-kilometer arcs were considered insufficient to facilitate a detailed analysis with respect to the meteorological parameters and hence were not used here.

In Figure 16 the results of the St. Louis experiments are compared with results of similar work in other areas. The grouping of the St. Louis, Johnstown, and Fort Wayne data herein was by Pasquill-Turner stability classes (Turner, 1964), which are merely more objective expressions of the Pasquill classes in terms of readily available meteorological variables. The solid curves are based upon data ordered by the Pasquill stability classes (Pasquill, 1961); those in 16a. and 16b. were originally presented by Gifford (1961) and in 16c. by Hilsmeier and Gifford (1962).

Particularly in Figures 16a and 16b, note that the best-fit lines for σ_y and σ_z for the St. Louis data are everywhere larger than those for the open-country counterparts. When extrapolated to longer downwind distances, the best-fit lines for σ_y approach their counterparts; those for σ_z generally approach counterparts of stability one class higher. In Figure 16c, the dilution of $(\chi/Q)_p \bar{u}$ in St. Louis over that in

open country is greatest near the source and is greater for stable than for unstable meteorological conditions, as expected (Figures 16a and 16b). Overall relations similar to those in Figure 16 are generally noted in Figures 15 and 17 despite the differences in terrain, sensor exposures, and response characteristics of equipment used in the various studies. Some of the apparent differences in Figure 17 can also be accounted for by the fact that Pasquill-Turner class A's and F's, which constitute a sizable fraction of the Brookhaven B_2 and D class members, respectively, were seldom represented in the data collected in the St. Louis experimental series.

Values of dispersion parameters obtained in fluorescent particle tracer experiments in Johnstown, Pennsylvania (Smith, 1967), and Fort Wayne, Indiana (Csanady et al., 1967), are also presented in Figure 16. The values are similar to those obtained in St. Louis under the same overall meteorological conditions. In Johnstown, dissseminations were from a low-level point source in the urban area; in Fort Wayne they were from a 90-meter-high, cross-wind line source located 1 mile upwind of the urban area. Values of σ_z for this elevated line source that were reported for the 1-mile downwind distance (i.e., at the upwind edge of the urban area) are not shown here; a direct comparison of the other values, particularly for shorter distances, with those of low-level sources can be questioned since the effects of local obstructions may not have become significant until the tracer plume reached near ground level.

For the St. Louis experiments a ratio of peak to mean concentrations (P/M) was computed for each case in which the appropriate sequential sampler was on or quite near the mean centerline of a tracer cloud. The ratios were formed from the peak and arithmetic average (mean) values of concentration of the time-concentration histograms; intervals of beginning and ending "dribble" were excluded. Plots of P/M as a function of downwind distance and travel time showed little variability, even when data were separated according to stability. Gifford (1960) presents similar results for ground-level emission sources.

A plot of P/M as a function of the ratio of averaging time, t_a, to sampling time, t_s, is shown in Figure 18. Averaging time is the time interval required for passage of the tracer cloud, excluding beginning and ending dribble. Sampling time is the finite time increment, usually 1 or 2 minutes, over which the peak concentration was measured. In this figure, P/M values show a very slight tendency to increase with increasing t_a/t_s. The values of P/M vary from about 2 to 6. Gifford (1960) shows similar values for ground-level sources; Singer et al. (1963) found that values decreased in proportion to increasing density of vegetation near receptors.

INITIAL DIMENSIONS OF TRACER CLOUD

The effects of a building upon a plume generated in its vicinity have been studied extensively in wind tunnel experiments (e.g., Halitsky, 1963). More recently, a full-scale investigation was conducted in the atmosphere (Dickson et al., 1967). Essentially, these studies show that the primary effect is an enhancement close to the source of the size of the plume, hereafter referred to as the initial size of the plume.

Pasquill-Gifford (Gifford, 1961) "C" stability curves (e.g., see Figure 16) for σ_y and σ_z and revised curves allowing for virtual travel distances corresponding to the specified initial cloud dimensions are presented in Figure 19. To facilitate comparisons, the best-fit "C" lines for the St. Louis tracer data (Figure 16) are also shown. The data in Figures 16 and 19 along with those in 15 and 17 indicate that the effect of the city on dispersion in the cross-wind is similar to the recognized effect of a single building near the source, although more complex. When the cloud becomes much larger than eddies created by the local obstructions, the extent of the dispersion, or rather σ_y, closely converges to that associated with open-country flow; the initial enhancement of plume size is presumably dependent on the width and height of the obstructions. A large initial dimension of the cloud and considerably enhanced dispersion is indicated in the vertical. The enhancement in the rate of dispersion over that in open country is greater in stable than in unstable meteorological conditions and is presumably due largely to enhanced convective activity over the urban environs.

In Figure 19, estimates of 50 to 60 meters for an initial σ_y and 20 to 30 meters for an initial σ_z for the somewhat diverse St. Louis locations appear reasonable. Relationships for the other stability classes are similar to those for "C." A Gaussian plume from a ground-level point source with an initial depth (2.15 σ_z, where plume edge = $1/10\ (\chi/Q)_p$) equivalent to the average building height of 40 to 50 meters in downtown St. Louis would have a σ_z value of approximately 20 meters. For a similar plume with an initial width (4.3 σ_y) equivalent to the length of a typical city block (160 meters), a σ_y of roughly 40 meters would result; if the plume were oriented with the cross-wind direction diagonally across such a block, the initial value of σ_y would increase to about 60 meters. Particularly in the downtown and older residential areas of cities, streets usually constitute the only significant relief between structures.

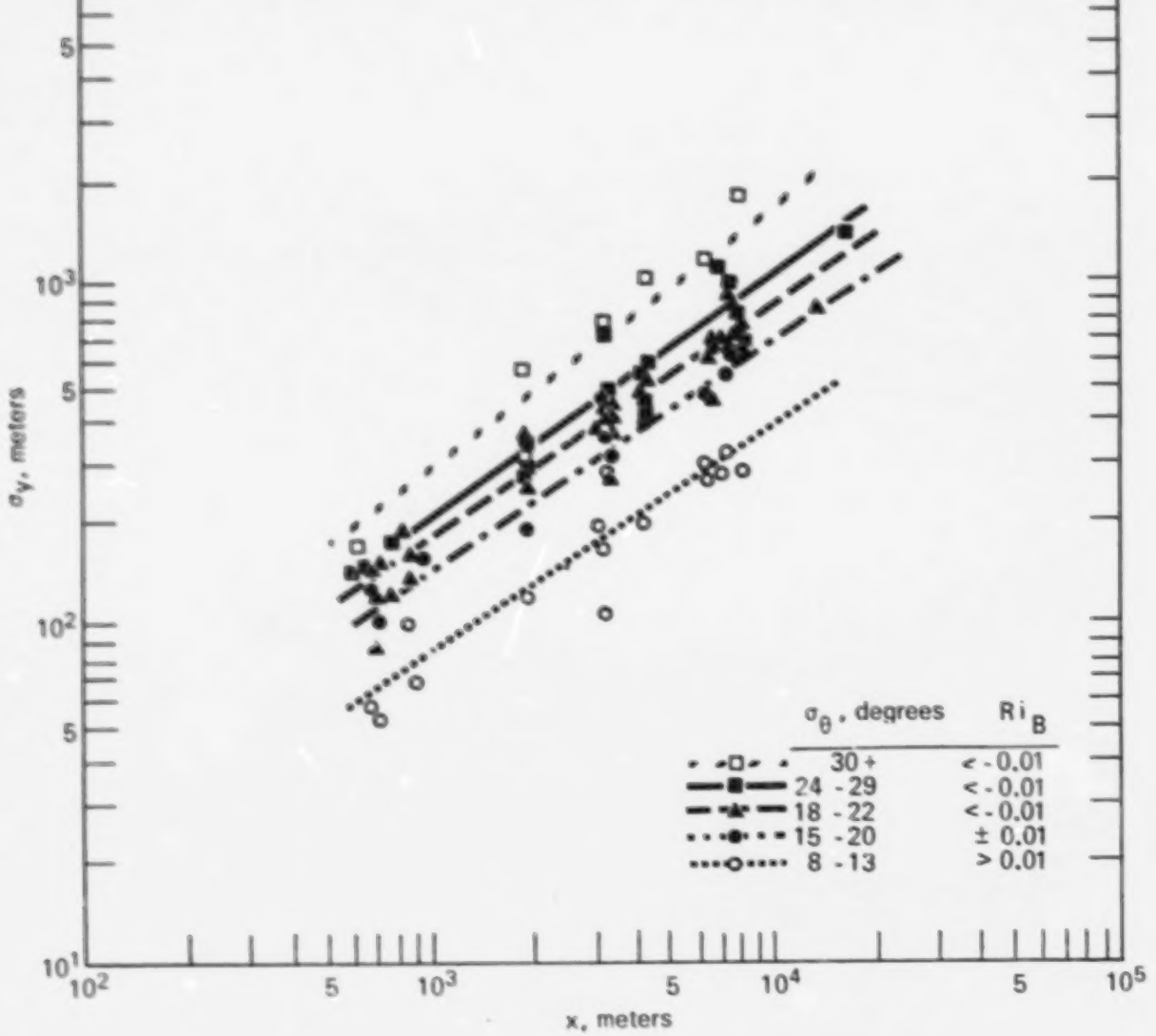


Figure 1. Cross-wind standard deviation of tracer material as a function of downwind distance in terms of standard deviation of wind direction fluctuations (σ_θ) and bulk Richardson number (Ri_B).

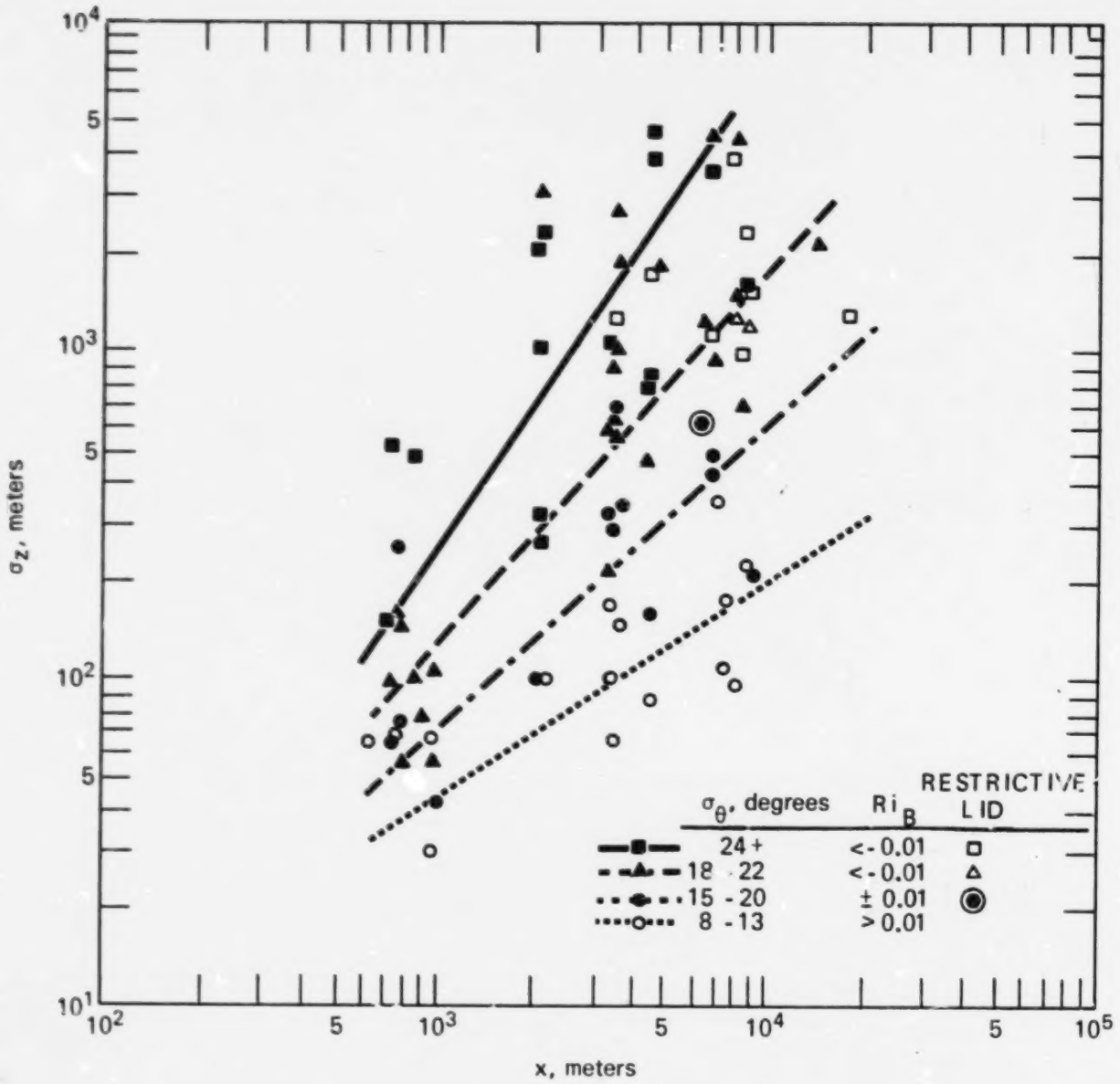


Figure 2. Effective vertical standard deviation of tracer material as a function of downwind distance in terms of standard deviation of wind direction fluctuations (σ_θ) and bulk Richardson number (Ri_B).

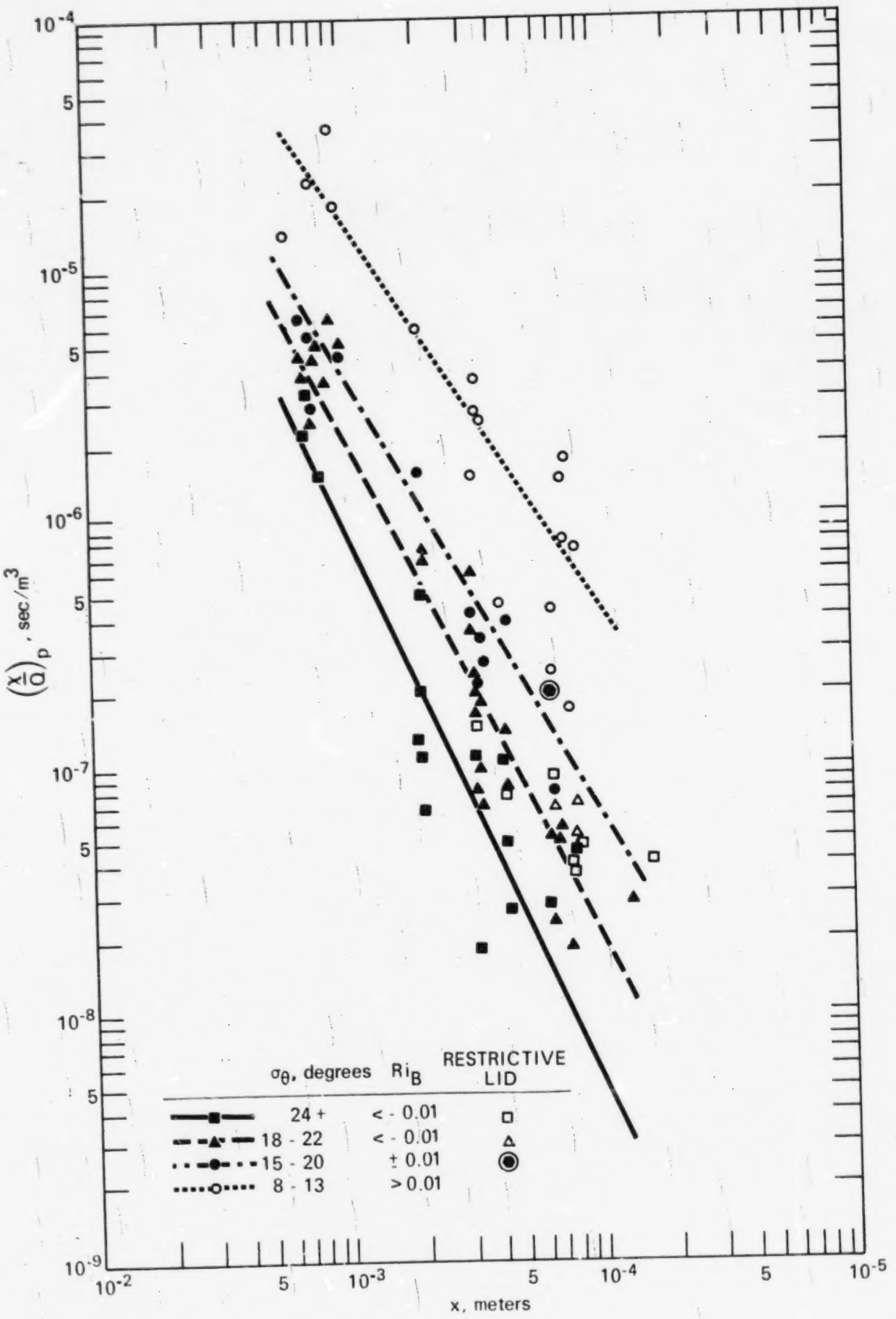


Figure 3. Relative axial concentration as a function of downwind distance in terms of standard deviation of wind direction fluctuations (σ_θ) and bulk Richardson number (Ri_B).

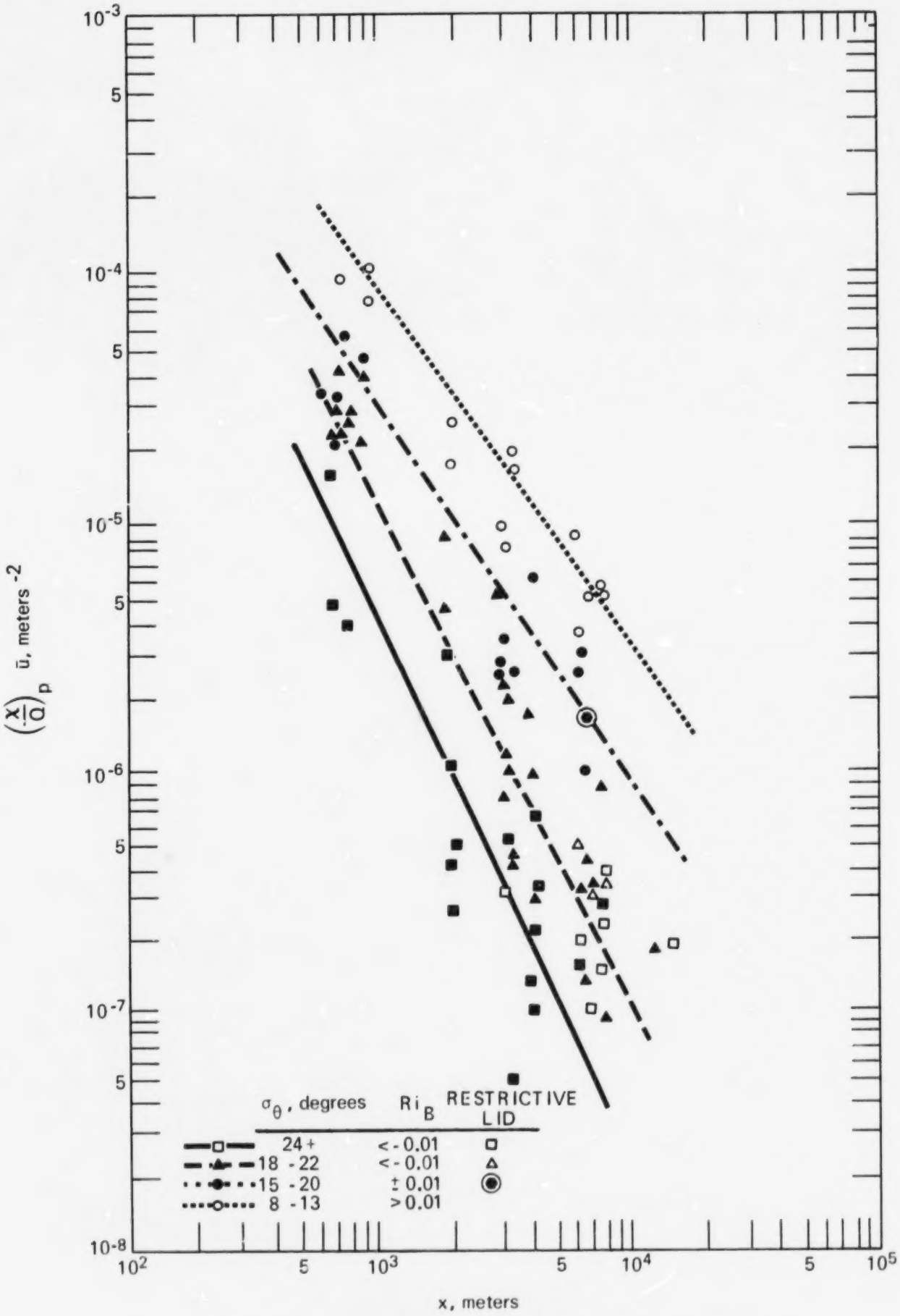


Figure 4. Normalized relative axial concentration as a function of down-wind distance in terms of standard deviation of wind direction fluctuations (σ_θ) and bulk Richardson number (Ri_B).

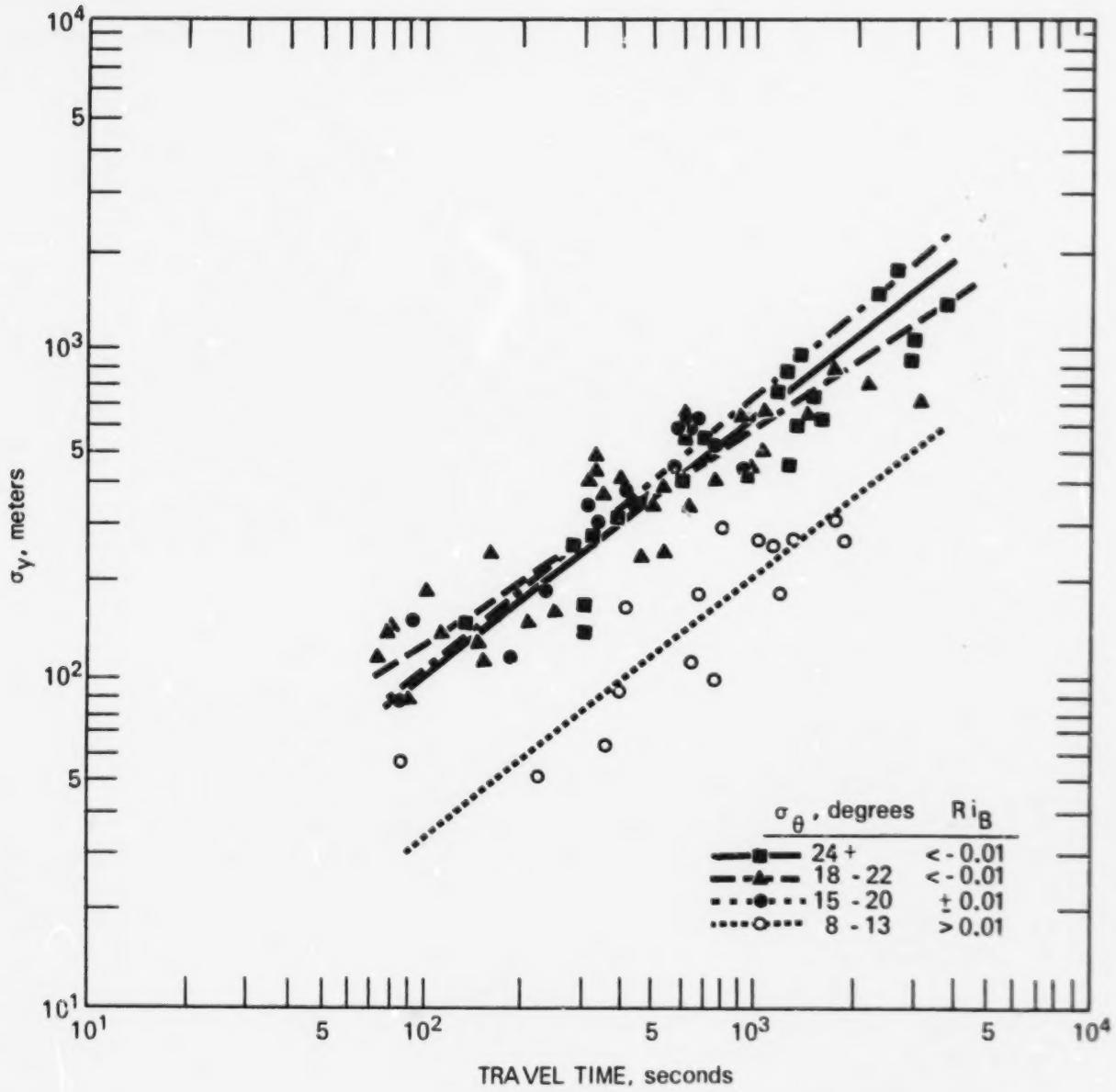


Figure 5. Cross - wind standard deviation of tracer material as a function of travel time in terms of standard deviation of wind direction fluctuations (σ_θ) and bulk Richardson number (Ri_B).

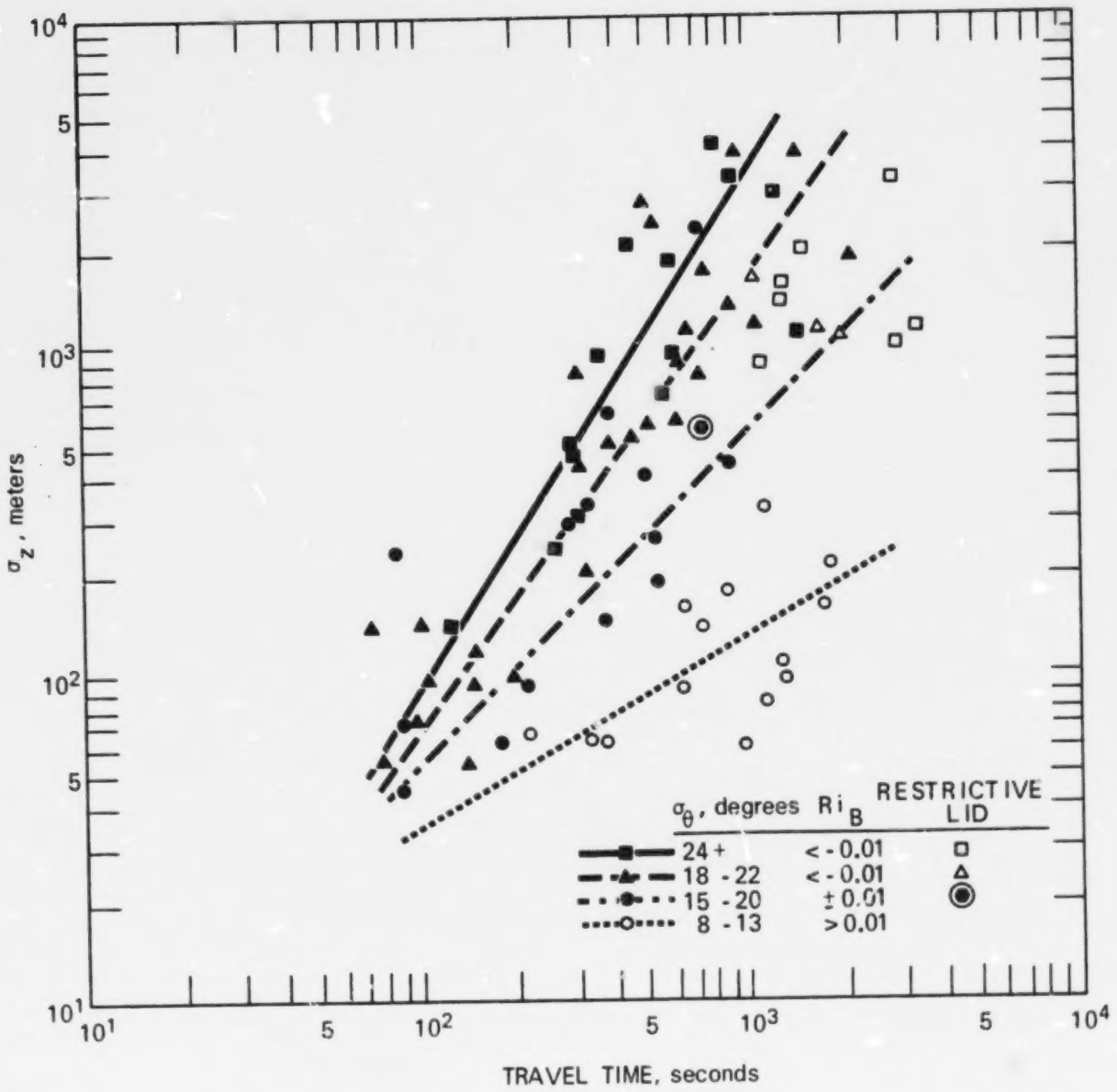


Figure 6. Effective vertical standard deviation of tracer material as a function of travel time in terms of standard deviation of wind direction fluctuations (σ_θ) and bulk Richardson number (Ri_B).

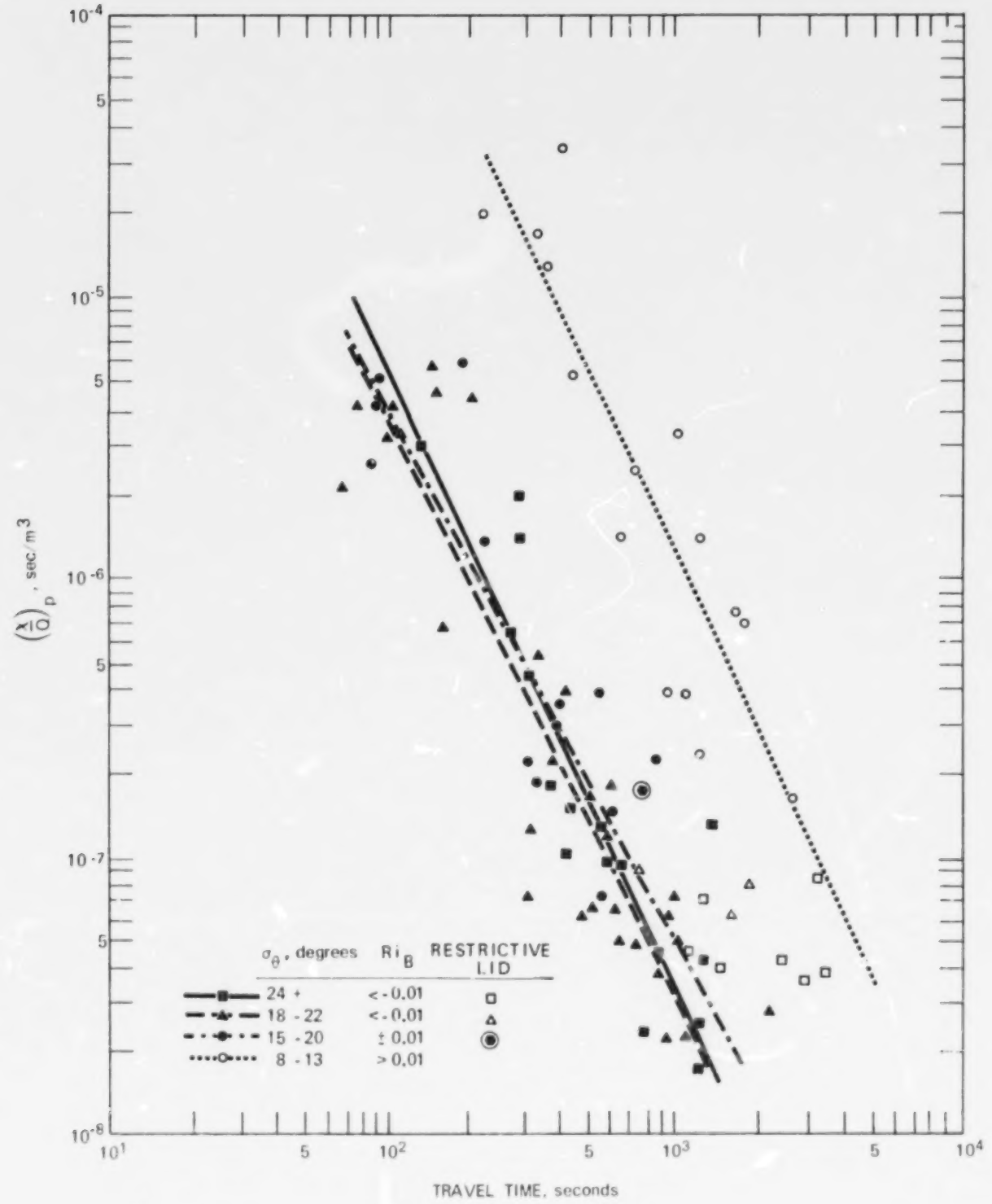


Figure 7. Relative axial concentration as a function of travel time in terms of standard deviation of wind direction fluctuations ($\sigma\theta$) and bulk Richardson number (Ri_B).

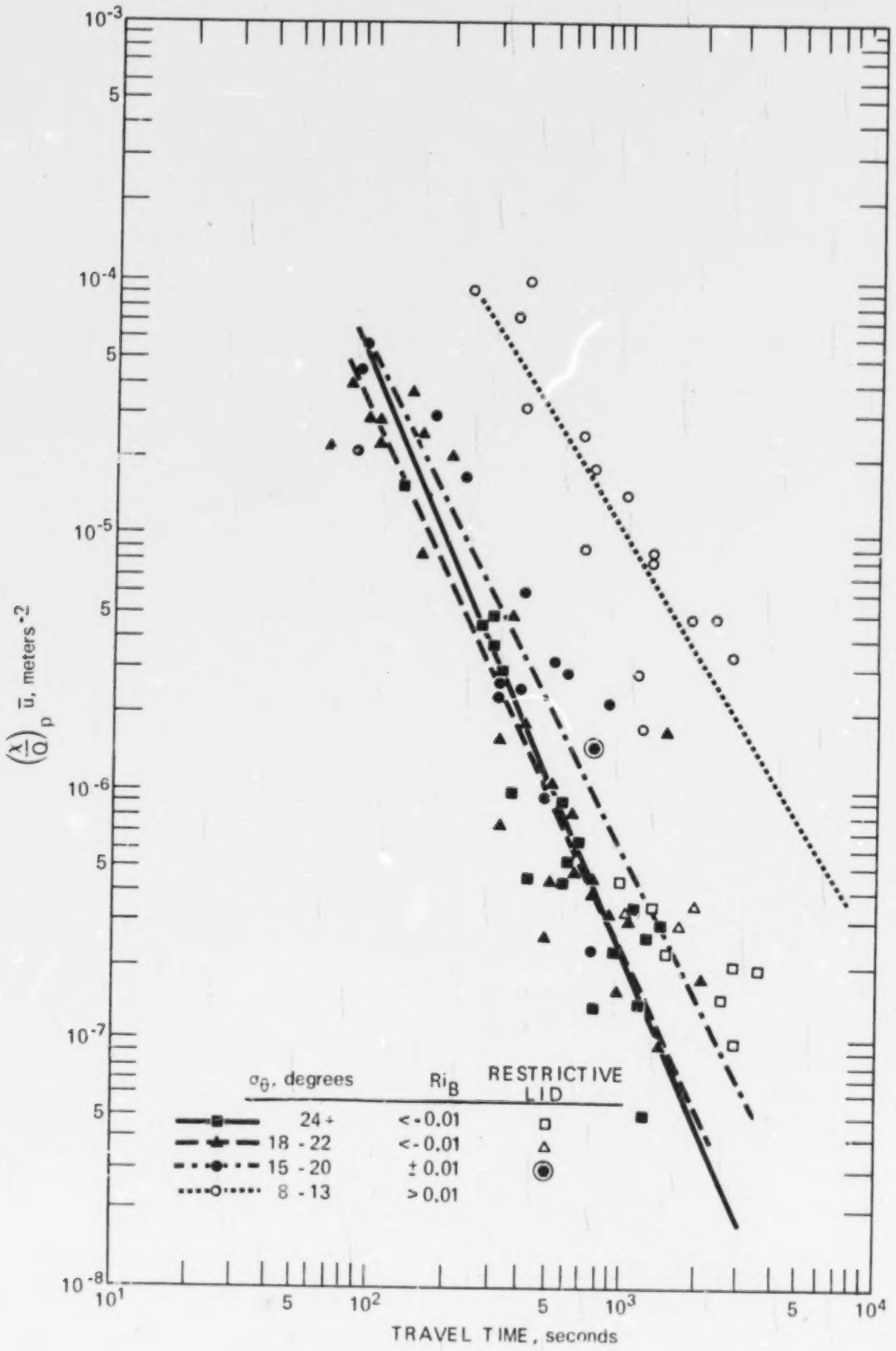


Figure 8. Normalized relative axial concentration as a function of travel time in terms of standard deviation of wind direction fluctuations (σ_θ) and bulk Richardson number (Ri_B).

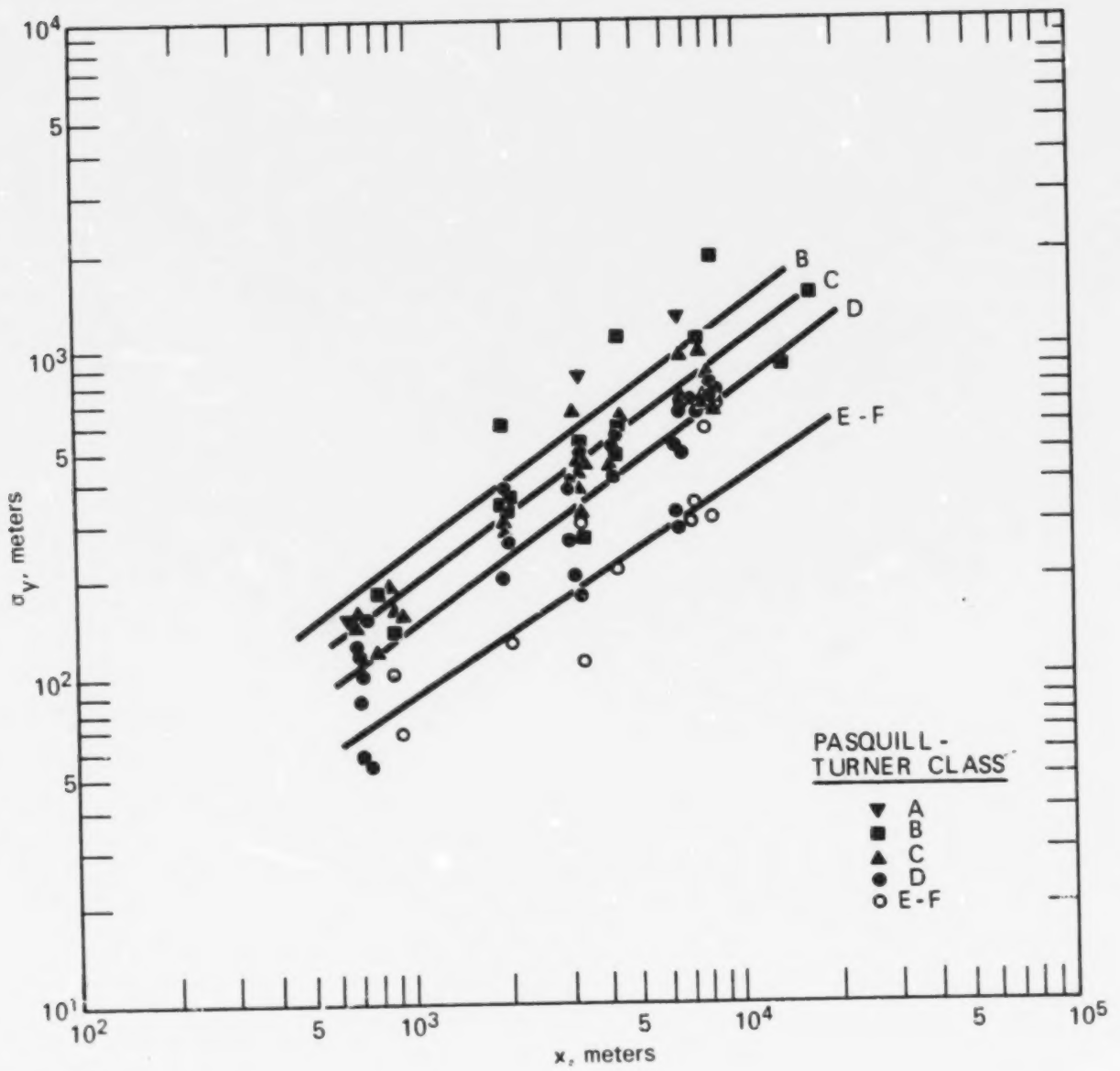


Figure 9. Cross -wind standard deviation of tracer material as a function of downwind distance in terms of Pasquill - Turner stability classes.

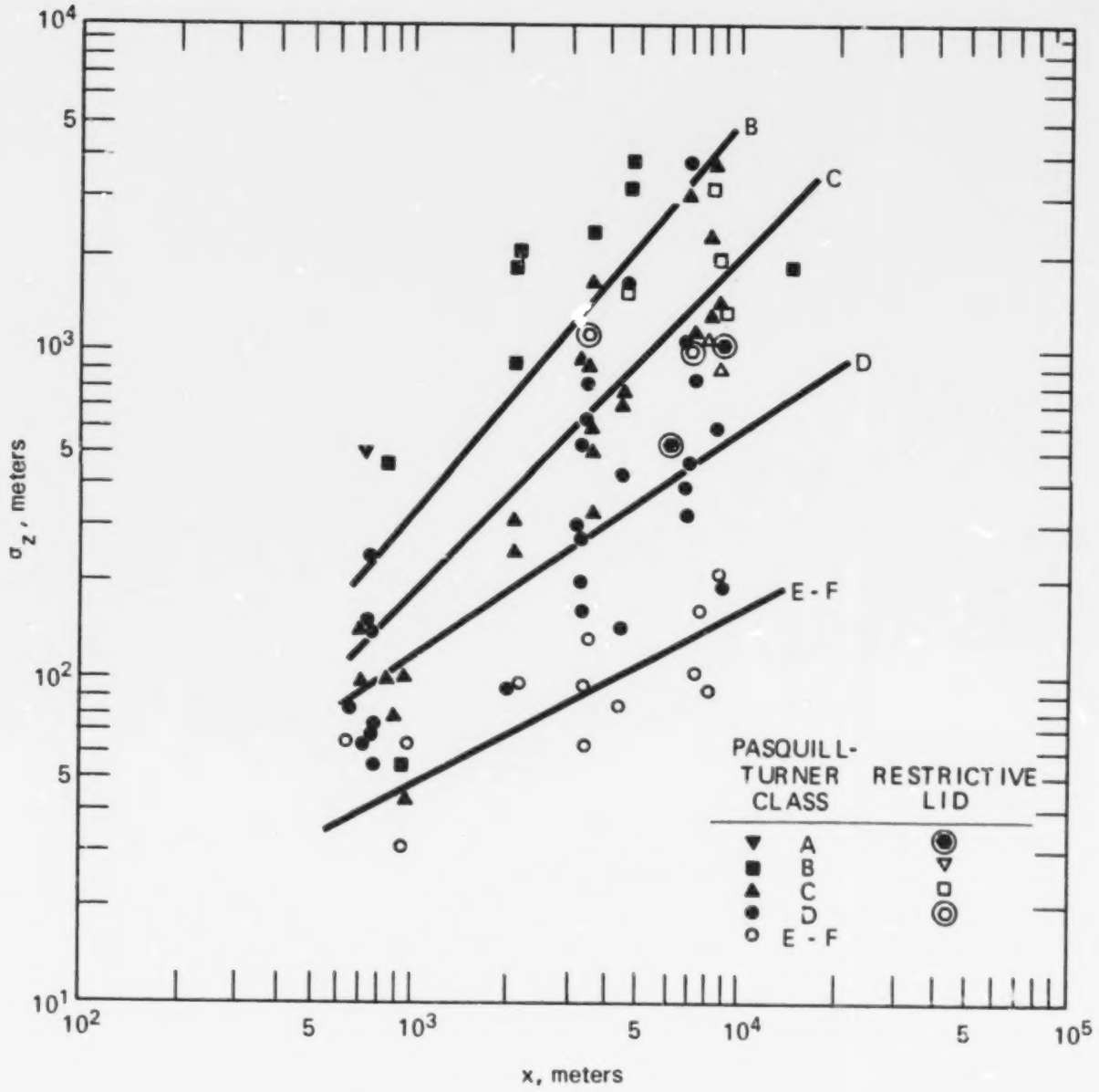


Figure 10. Effective vertical standard deviation of tracer material as a function of downwind distance in terms of Pasquill - Turner stability classes.

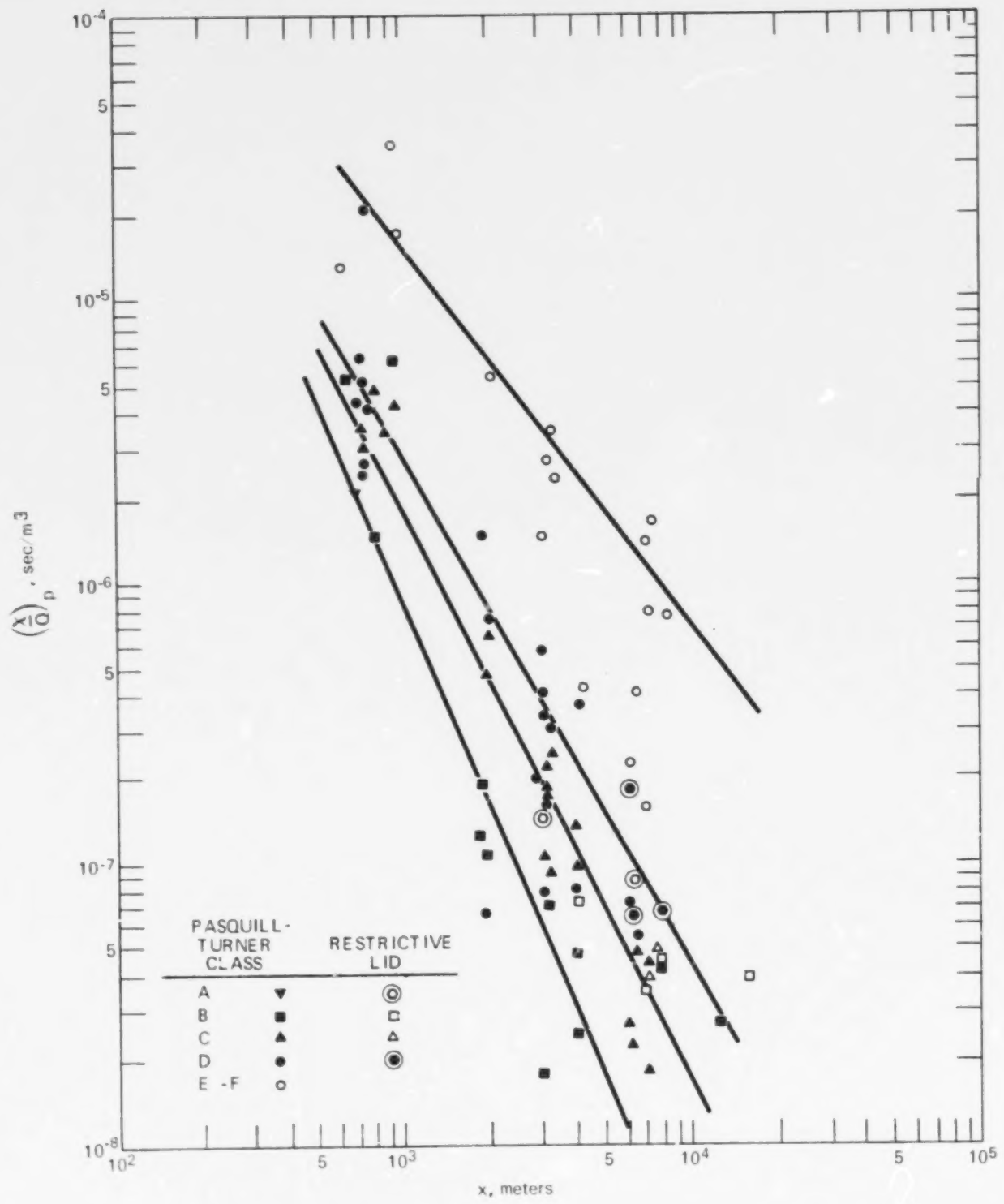


Figure 11. Relative axial concentration as a function of downwind distance in terms of Pasquill - Turner stability classes.

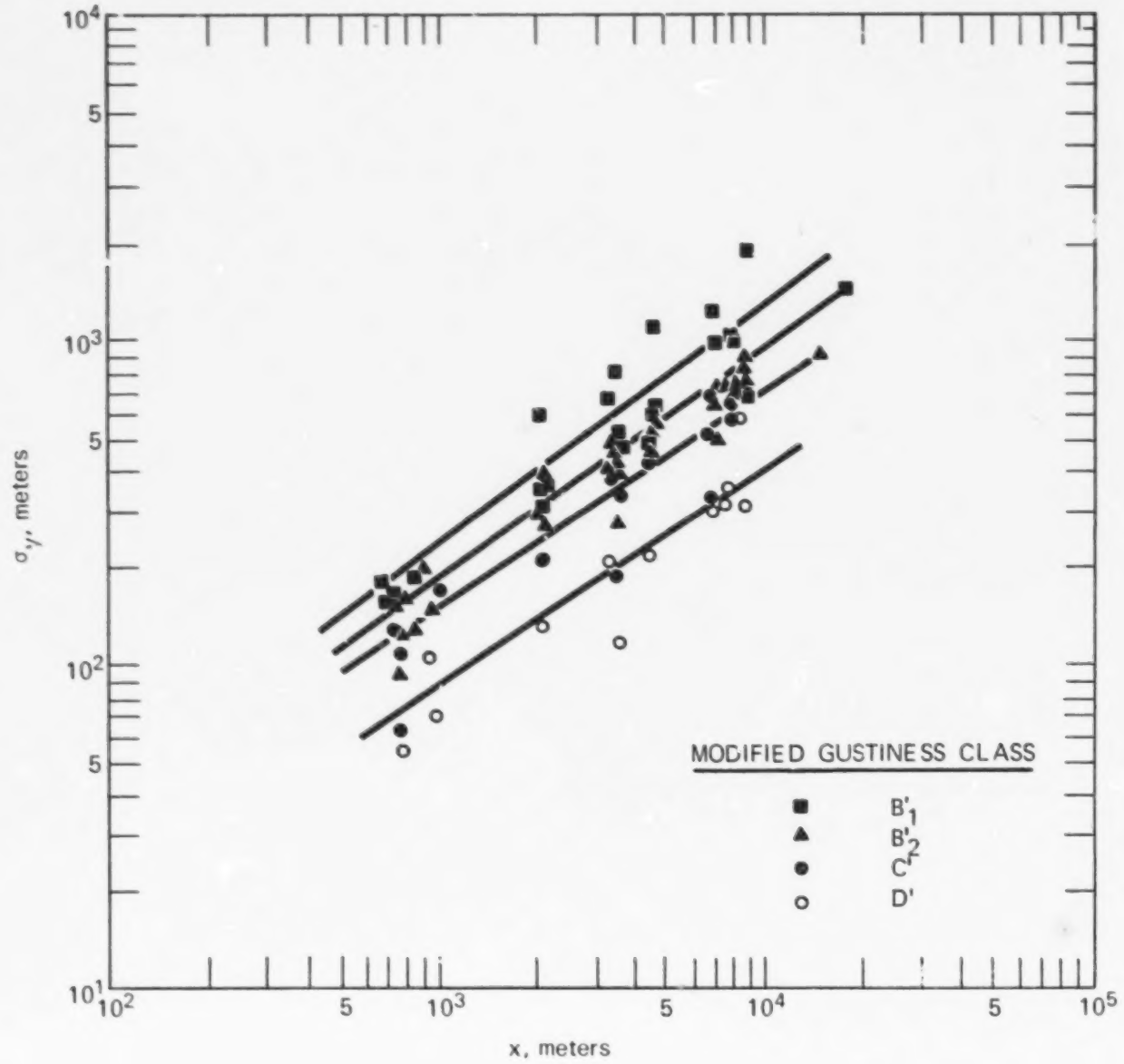


Figure 12. Cross - wind standard deviation of tracer material as a function of downwind distance in terms of modified Brookhaven gustiness classes.

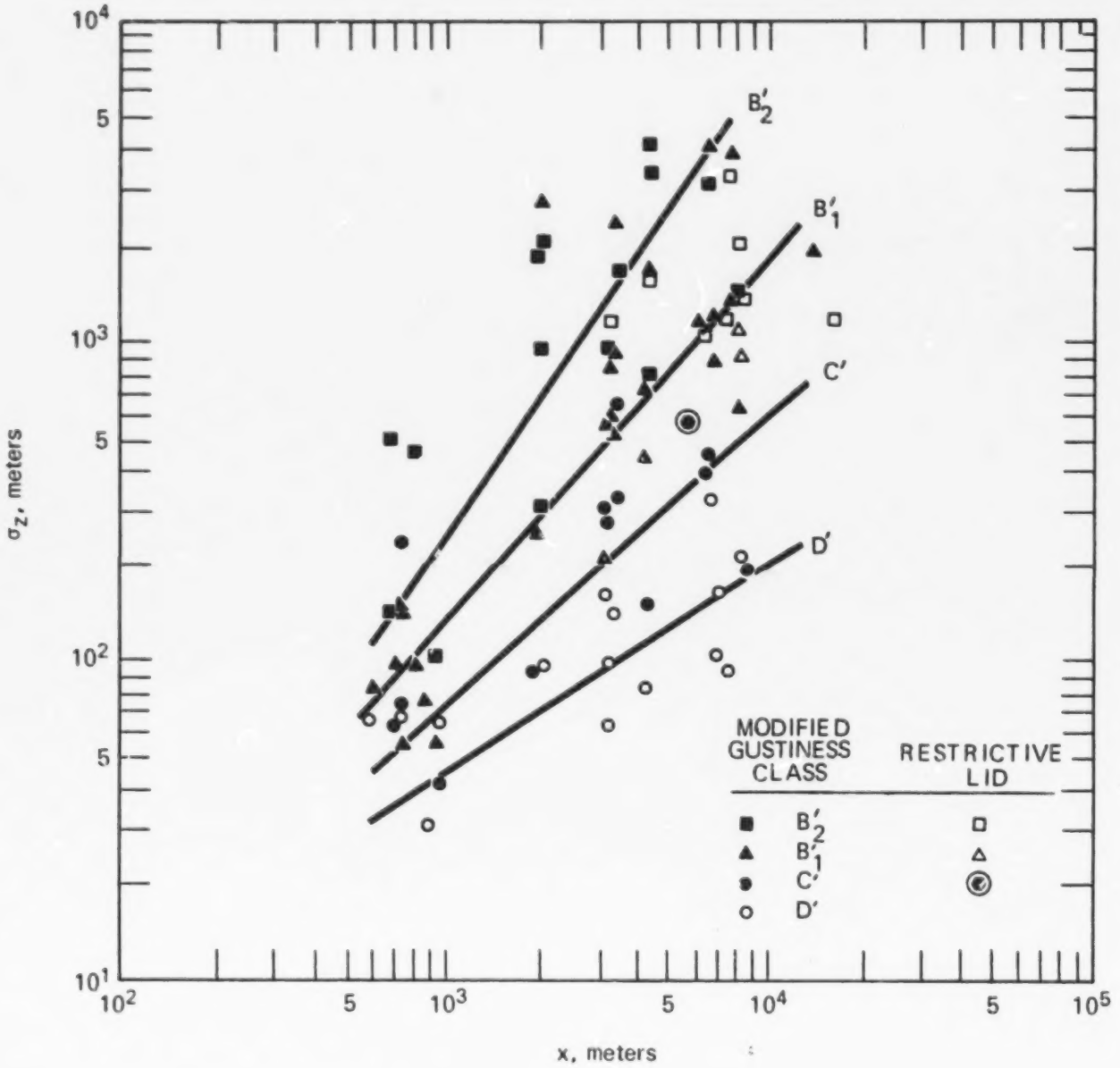


Figure 13. Effective vertical standard deviation of tracer material as a function of downwind distance in terms of modified Brookhaven gustiness classes.

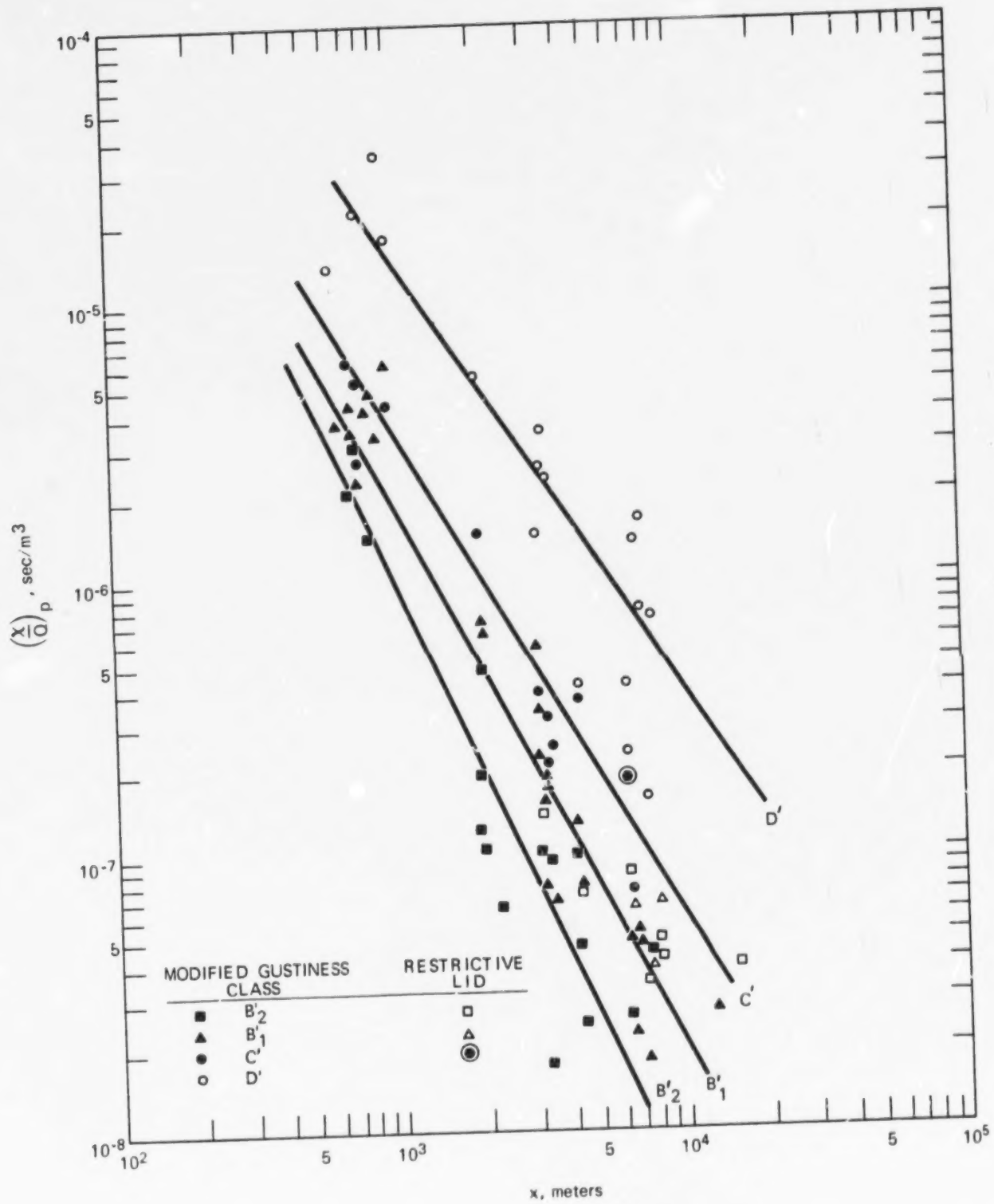


Figure 14. Relative axial concentration as a function of downwind distance in terms of modified Brookhaven gustiness classes.

Initial Dimensions of Tracer Cloud

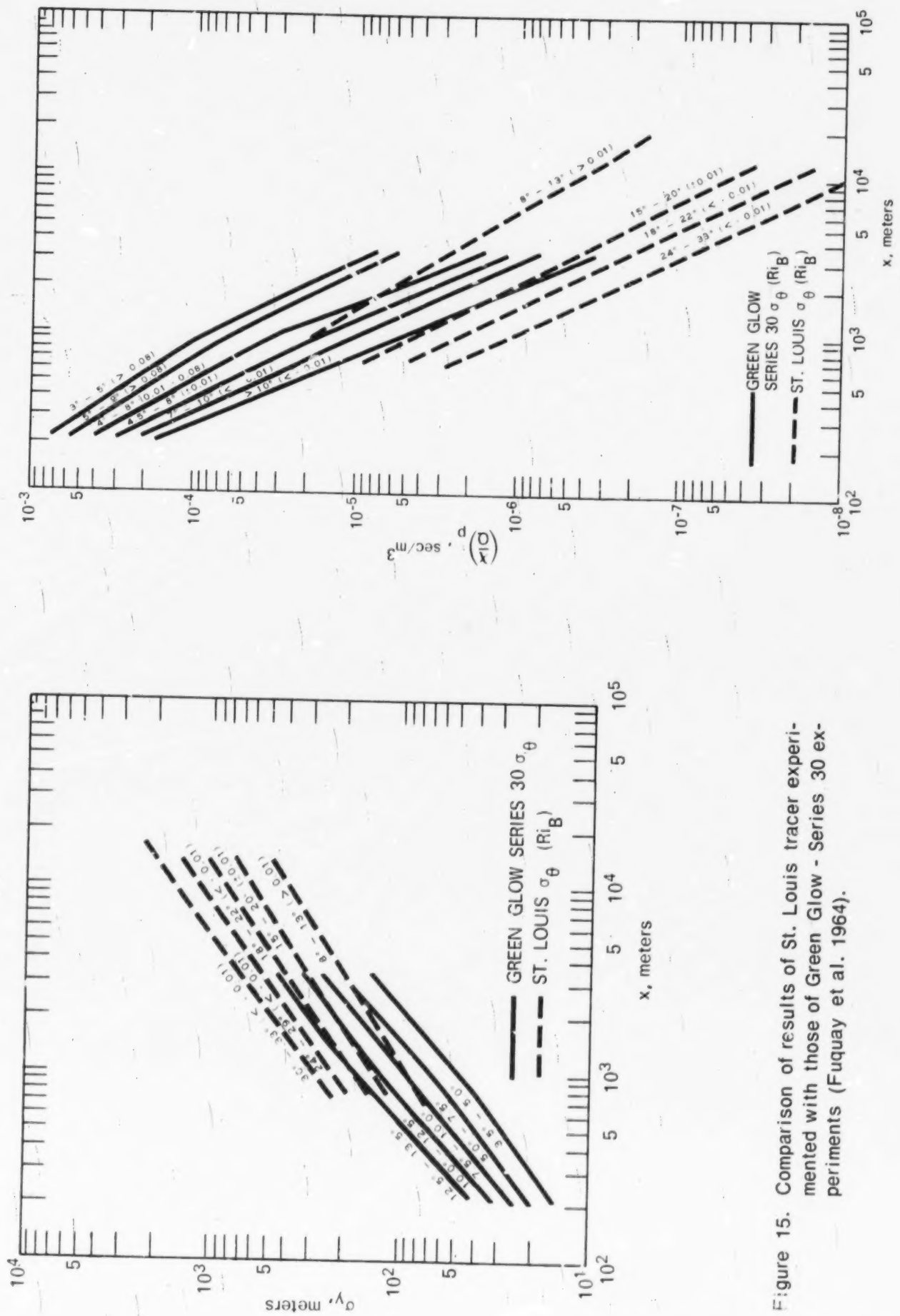

GREEN GLOW SERIES 30 σ_θ (Ri_B)
ST. LOUIS σ_θ (Ri_B)
3° – 5° (> 0.08)
5° – 8° (> 0.08)
8° – 10 (0.01 – 0.08)
4.5° – 8° (< 0.01)
7° – 10° (< 0.01)
> 10° (< 0.01)
8° – 13° (> 0.01)
15° – 20° (< 0.01)
18° – 22° (< 0.01)
24° – 33° (< 0.01)
$\left(\frac{D}{\chi}\right)_p$, sec/m^3
σ_y, meters
x, meters

Figure 15. Comparison of results of St. Louis tracer experiments with those of Green Glow - Series 30 experiments (Fuquay et al. 1964).

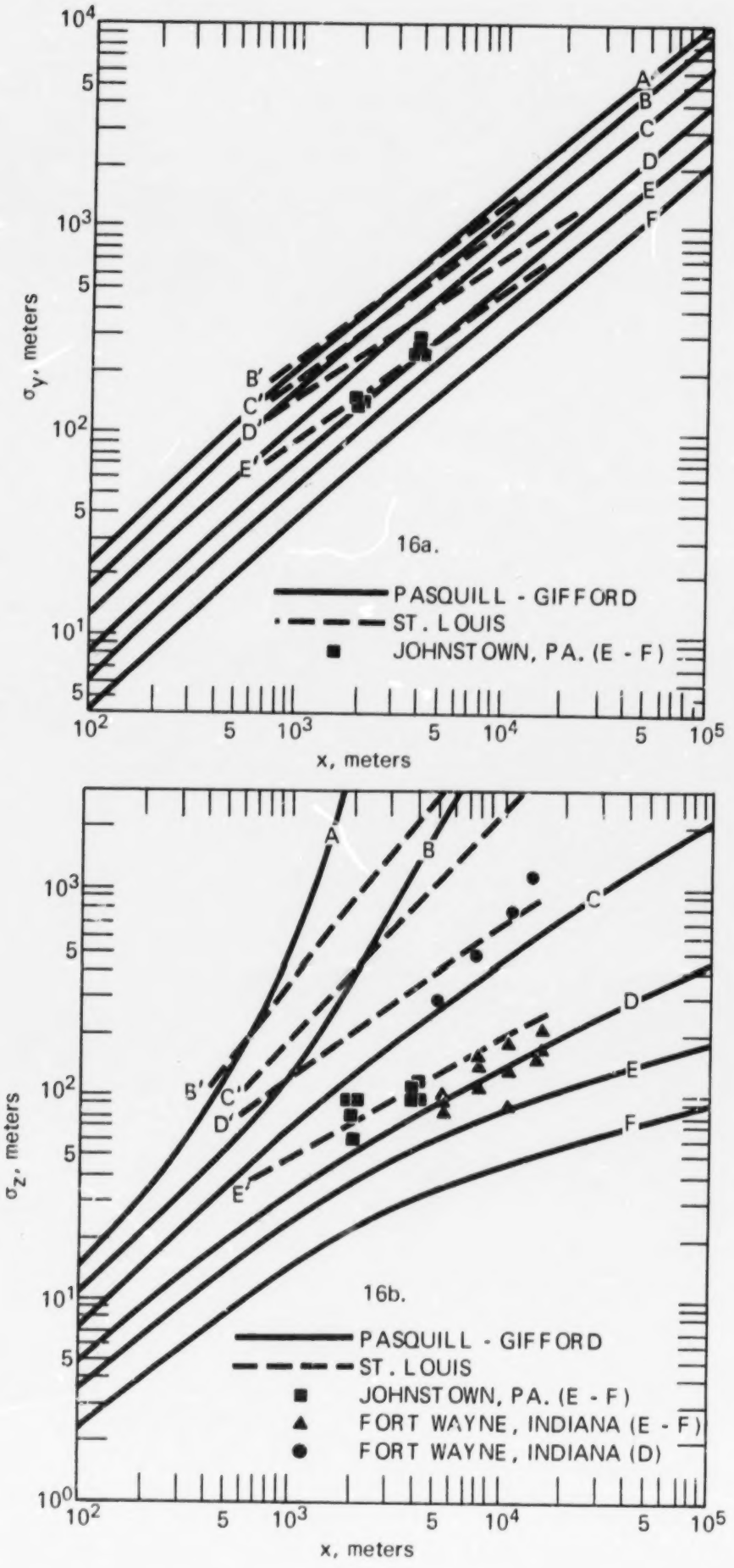


Figure 16 (a and b). Comparison of the results of the St. Louis and other urban tracer experiments with those summarized by Pasquill and Gifford (1961).

Initial Dimensions of Tracer Cloud

Note:
The grouping of the St. Louis, Johnstown, and Fort Wayne data in Figure 16 was by Pasquill-Turner stability classes (Turner, 1964), which are really only more objective expressions of the Pasquill stability classes (Pasquill, 1961) in terms of readily available meteorological variables. The solid curves are based upon data ordered by the Pasquill stability classes; those in Figures 16a and 16b were originally presented by Gifford (1961), and those in Figure 16c by Hilsmeier and Gifford (1962).

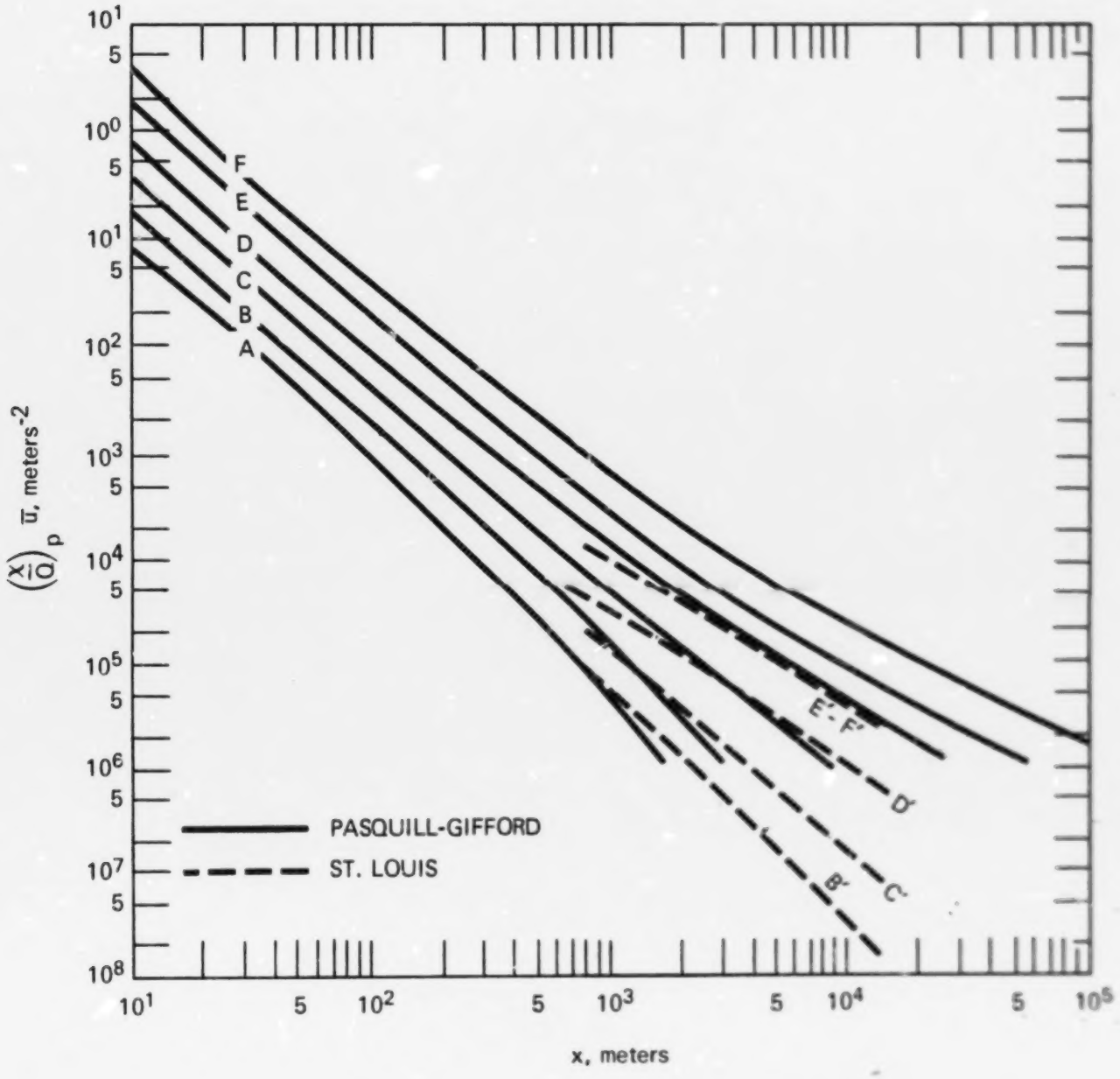


Figure 16 (c). Comparison of the results of the St. Louis tracer experiments with those summarized by Pasquill and Gifford (1961).

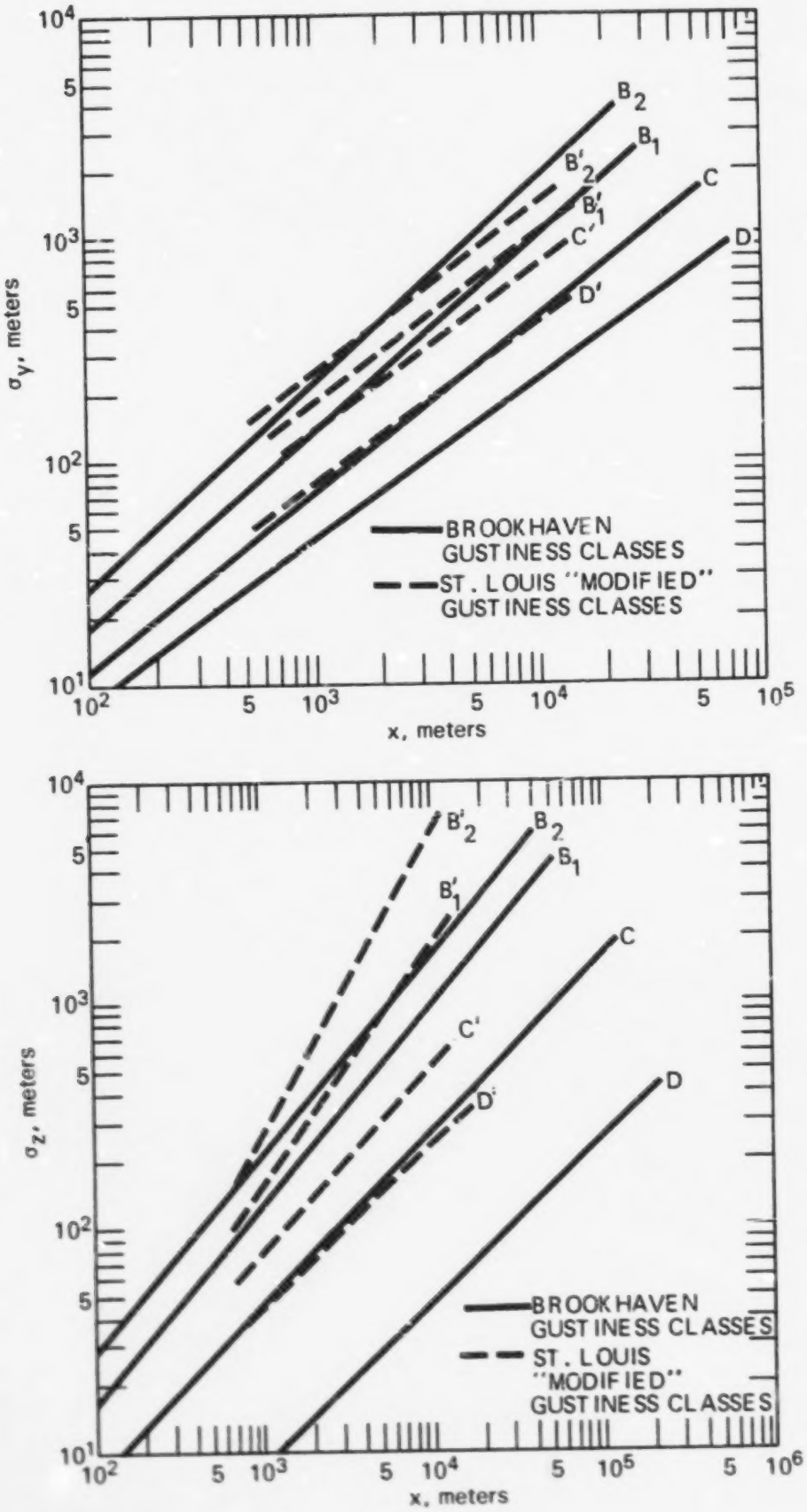


Figure 17. Comparison of results of St. Louis tracer experiments with those of Brookhaven experiments (Singer and Smith, 1966).

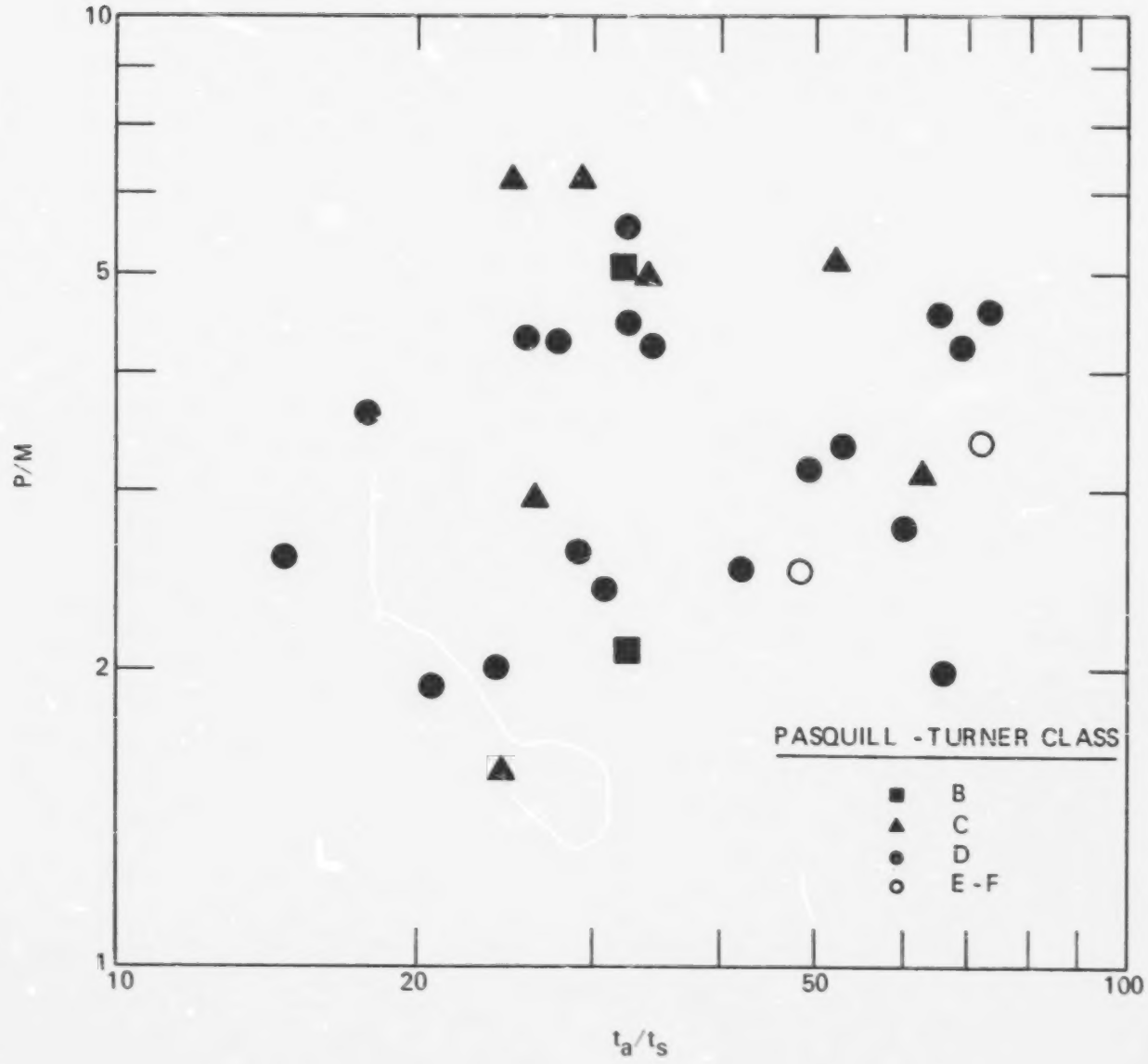
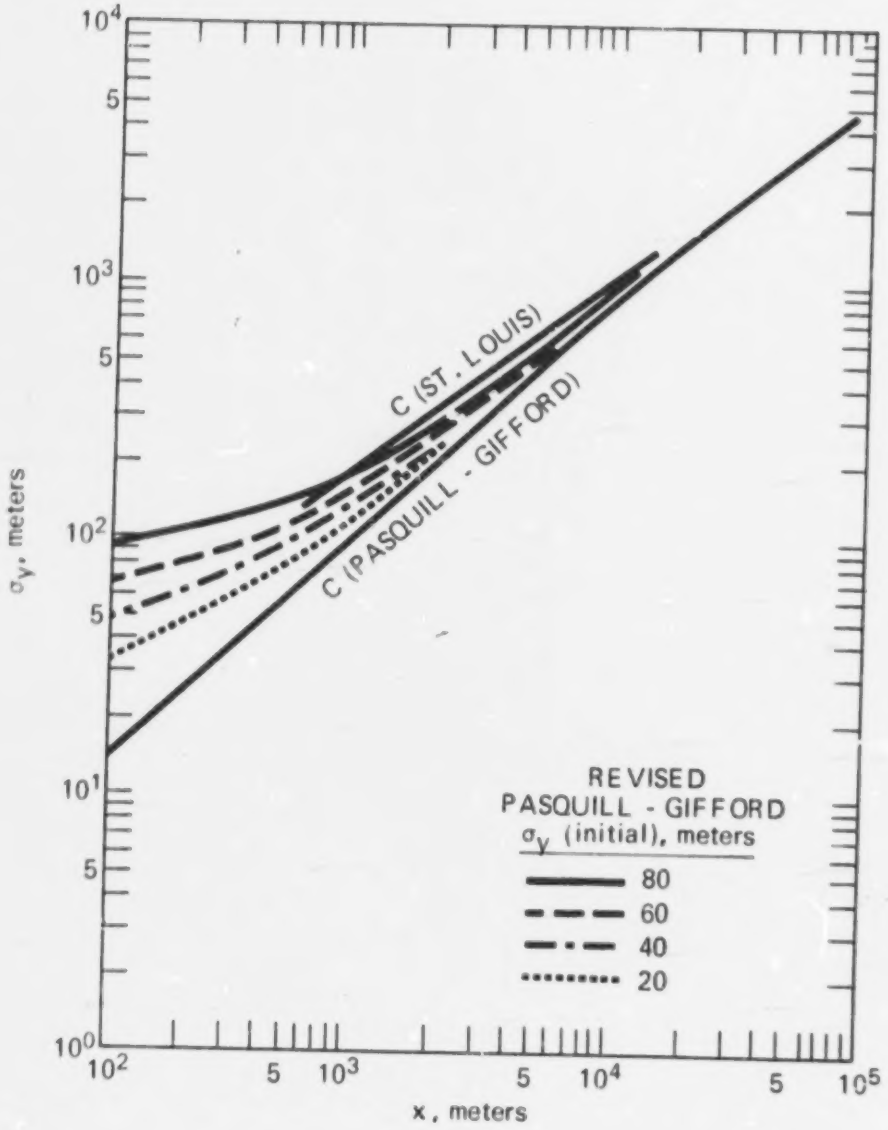


Figure 18. Ratio of peak to mean concentration as a function of ratio of averaging time to sampling time.



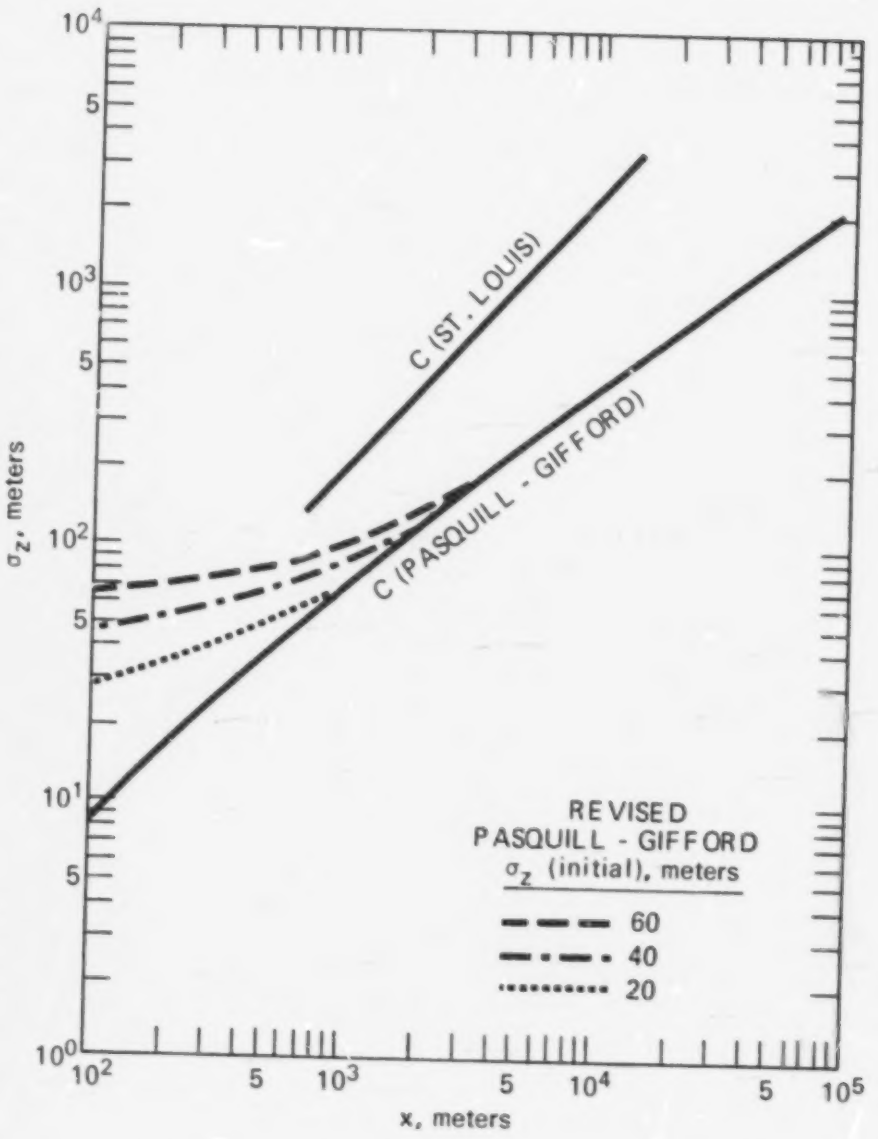


Figure 19. Comparison of Pasquill - Gifford "C" stability curves (Gifford, 1961), revised to allow for specified initial plume dimensions, with best - fit lines for St. Louis tracer data.

CONCLUSIONS AND RECOMMENDATIONS

Results of the St. Louis Dispersion Study reported here support the following conclusions regarding dispersion of airborne material emitted from low-level point sources in urban areas:

1. Dispersion can be readily described by commonly utilized meteorological indices of turbulence. The more detailed indices for urban locations appeared to be most representative.

2. In terms of the meteorological indices of turbulence, cross-wind dispersion is better described as a function of downwind distance than of travel time, whereas vertical dispersion is described about as well by travel time as by downwind distance. It should be noted, however, that Pooler (1966) found, for an overall classification of experiments simply as daytime or evening, that cross-wind dispersion was expressed about as well in terms of travel time as of downwind distance, whereas vertical dispersion was expressed better in terms of travel time.

3. The urban area affects cross-wind dispersion primarily by enhancing the size of the initial plume. When the plume becomes much larger than the size of eddies created by the local obstructions, the extent of the dispersion approaches that associated with flow over open country. In the vertical, significantly enhanced dispersion as well as a large initial spread of the plume result: the enhancement in the rate of dispersion over that in open country is somewhat greater for stable than for unstable meteorological conditions and, presumably, is due largely to enhanced convective activity over the urban environs.

4. Restrictive mixing layers (e.g., inversion aloft) can significantly alter the values of affected vertical dispersion parameters and concentrations of airborne material near the surface.

Dispersion from low-level sources in urban areas for downwind distances of less than about 1/2 mile is conjectural. Here, the effects of local roughness elements should be most pronounced. Specifically, initial cloud dimensions as affected by factors such as building width and height and building density should be ascertained, and the effects of complexes rather than single structures should be catalogued.

The effects of urban areas on dispersion of plumes from elevated sources, particularly at the shorter downwind distances, may differ markedly from those suggested for lower-level sources, and hence may require independent investigation. As mentioned earlier, the effects

of local obstructions may not become significant until a plume nearly reaches the ground. At this point the plume may also be so large that the locally created eddies are not significantly effective in dispersing it. In addition, as the effective source height increases, different stability regimes about which little is known are encountered.

The analyses reported herein concerning data collected during the St. Louis Dispersion Study are not considered to be exhaustive. It is hoped that the body of data can serve a useful purpose for the application of more advanced analytical techniques, which are certain to be developed by meteorological science in the future.

ACKNOWLEDGMENTS

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